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ON THE SPECTRA OF BORON

By R. A. Sawyer and F. R. Smith

Inspection of the previously published data on boron reveals less than a dozen spectral lines attributed to this element in the region of longer wave length than 1850 Angstrom units.[1,2] A consideration of the series spectra of the various stages of ionization of boron however shows that a considerably larger number of lines is to be expected in this region. The present work was undertaken to see whether with the vacuum spark as a source and spectrographs of medium dispersion some of these lines could be found.

I. APPARATUS AND PROCEDURE

The apparatus for the production of the vacuum spark has been described by Sawyer and Paton.[3] In the present work, however, the

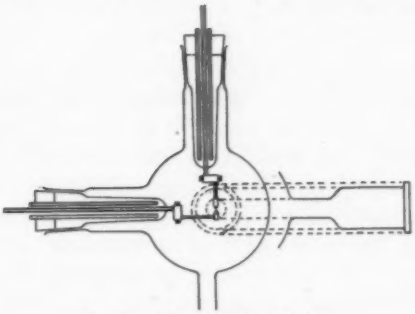

Fig. 1. *Diagram of spark-box.*

metal spark-box there used was replaced by a glass one of new design which was found to be much more convenient. (Fig. 1.) Arms about four inches long and one and one-half inches in diameter were attached,

[1] H. Kayser, Handbuch der Spectroscopie, *5*, *6*, *7*.
[2] A. Fowler, Report on Series in Line Spectra, p. 155.
[3] Astrophysical Journal, *57*, p. 279; 1923.

one to the bottom and one to the side of a two-liter Pyrex glass flask. These arms were fitted with hollow ground-glass stoppers which projected nearly to the center of the box. A hundred mil tungsten lead wire was sealed in each of the stoppers. Glass tubes placed around the leads inside the stoppers gave greater dielectric strength. A wire of sufficient length to reach to the center of the box was attached to each lead. About one inch of the extremity of the wire was bent at right angles and a spring clamp for holding the material to be sparked was mounted on the end of the wire. The arms formed by bending the wire allowed the sample to be moved through the arc of a circle when the stopper was rotated. Since the two arms carrying the electrodes were at right angles to each other considerable adjustment of the spark-gap could be made by rotating the stoppers without opening the spark-box. A tube about seven inches long and two and one-half inches in diameter projected from the bulb at right angles to each of the arms carrying an electrode. The end of this tube was ground flat and a quartz window was sealed to it through which the spark was observed. The long tube prevented sputtering of the window. The neck of the flask formed the outlet leading to the evacuating system which consisted of a Kurth type mercury vapor pump supported by a Cenco Hyvac fore-pump. A trap immersed in liquid air was placed between the spark-box and the pump to condense any water or mercury vapor present.

A small quantity of boron was available in the form of small rods which had been prepared by Weintraub. The resistivity of boron at ordinary temperatures is very high, Weintraub[4] giving its conductivity at 0°C as $0.5\text{–}0.6\times10^{-6}$ reciprocal ohms per cm as compared to 1.8 for silicon and 0.7×10^{6} for copper. This made it difficult to start a spark between boron electrodes. The spark-gap had to be made very small, less than one mm, and the discharge obtained was not as heavy as that produced by the same electrical circuit with metallic electrodes, or even with silicon. A much heavier spark was obtained when a piece of shell charcoal was used for one electrode. The resistance of boron decreases very rapidly as the temperature rises. For example Weintraub, loc. cit., gives the resistance of a certain sample of boron as 775000 ohms at 27°C but less than a hundred-thousandth of this value at about 500°C. On account of this large negative temperature coefficient of resistance the current would increase rapidly when the

[4] Journal Ind. and Eng. Chem., *5*, p. 106; 1913, Trans. Am. Electrochem. Soc., *16*, p. 165; 1909.

spark was once started and if the spark continued for any appreciable length of time the boron would become heated to incandescence and the electrodes would disintegrate. Also the heating would cause so much expansion that the small gap would become closed, the electrodes would fuse together and would crumble when separated. As the supply of boron was very limited it was necessary to watch the sparking constantly to prevent these occurrences. A hand-operated switch in the primary circuit of the transformer was located near the spark-box to control the interval between the sparks and their duration. This switch could be closed only a fraction of a second, perhaps one-half, while enough time, one or two seconds, had to be allowed to elapse between successive sparks so the electrodes could cool below the temperature of incandescence. Even with the greatest care the electrodes would usually crumble and have to be replaced two or three times during an exposure.

II. DATA

Spectrograms were taken in the region λ2300–λ4200 with a Hilger E2 quartz spectrograph using Cramer contrast plates oiled with Nujol and in the region λ3800–λ5800 with a two prism glass spectrograph built in the Physics department shops at the University of Michigan. The iron arc spectrum was used as a standard. The plates were measured on a Gaertner comparator and reduced by the Hartmann formula.

The data were checked for gaseous impurities against the vacuum spark data obtained in the laboratory on other elements and against the published lists of spectra of suspected elements. The chief impurities were iron from the clamps, calcium and hydrogen.

The spectral lines listed in Table 1 are thought to be all due to boron. All were measured on several plates and the wave lengths are considered to be accurate to one-tenth of an Angstrom unit or better, except possibly in the longest wave lengths.

TABLE 1. *Lines in the vacuum spark spectrum of boron.*

Intensity	Wave-lengths (In air)	Wave-numbers (In vacuum)	Classification
1	4940.87	20233.7	B II 3^3D-4^3P
1	4937.70	20246.7	
1	4901.85	20394.8	
0	4849.6	20614.3	B II 3^1D-4^1F

TABLE 1. *Continued.*

Intensity	Wave-lengths (In air)	Wave-numbers (In vacuum)	Classification
0	4829.0	20702.7	B II 3^1D-4^1P
0	4761.4	20996.5	B II 4^1F-8^1D ?
2	4677.9	21371.2	B III 4^3D-5^3P
5	4497.71*	22227.3	B III 4^3F-5^3G*
0	4493.1	22249.9	
2	4472.70*	22351.6	B II $3^3P_2-4^3S$*
2	4471.97*	22355.3	B II $3^3P_{0,1}-4^3S$*
1	4402.95	22705.7	
0	4394.25	22760.5	
2	4382.95	22809.3	
1	4375.60	22847.6	
1	4371.69	22868.1	
3	4355.68	22952.1	
1	4353.17	22965.3	
2	4344.77	23009.7	
2	4311.9	23185.2	B III 4^3P-5^3D
0	4290.90	23298.6	B II 3^1P-4^1P
0	4272.86	23397.0	
1	4231.07	23628.0 ?	
1	4226.15	23655.5	
0	4214.17	23722.8	B II 3^1P-4^1D
0	4201.86	23792.3	
1	4194.82	23832.2	
0	4192.72	23844.2	
2	4164.43	24006.2	
1	4150.71	24085.5	
10	4121.68*	24254.8	B II 3^3D-4^3F*
0	4090.79	24438.3	
1	4082.62	24487.2	
1	4050.13	24683.6	
2	4039.57	24748.1	
0	4027.82	24820.4	
1	4026.47	24828.7	
4	3871.39	25828.2	
0	3754.86	26624.6	
0	3493.85	28613.5	
25	3451.22*	28966.0	B II $2^1S-2^1P_1$*
5	3360.09	29752.6	
3	3323.34	30081.6	B II 3^1P-5^1S
3	3302.51	30271.3	
1	3282.01	30460.4	
3	3260.74	30659.1	B II 3^1D-5^1F
1	3191.84	31320.9	
0	3178.24	31454.9	

* Previously classified.

TABLE 1. *Continued.*

Intensity	Wave-lengths (In air)	Wave-numbers (In vacuum)	Classification
1	3158.54	31651.1	
1	3136.85	31870.0	B II $3^3P_2-4^3D$
1	3135.64	31872.1	B II $3^3P_{0,1}-4^3D$
1	3112.50	32119.2	
2	3102.09	32227.0	B II 3^3D-5^3P
1	3086.06	32394.4	
1	3013.28	33176.9	
1	2981.53 ?	33530.0	B II 3^1P-5^1D ?
1	2918.15*	34258.3	B II 3^3D-5^3F*
1	2889.72	34595.3	
1	2888.32	34612.0	
1	2886.80	34630.2	
1	2809.72	35580.2	
5	2785.14	35894.3	
8	2779.26	35970.2	
1	2749.89	36354.4	
1	2731.94	36593.2	
0	2698.35	37048.7	
0	2697.72	37057.4	
1	2696.84	37069.4	
2	2695.18	37092.3	
0	2694.23	37105.3	
0	2671.94	37414.9	
1	2652.81	37684.7	B II $3^3P_2-5^3S$
1	2652.58	37687.9	B II $3^3P_{0,1}-5^3S$
1	2610.26	38298.9	
1	2566.40	38953.4	B II 3^1P-6^1D
3	2566.26	38955.5	B II 3^1S-4^1P
2	2557.52	39088.6	
2	2515.06	39748.5	B II 3^3D-6^3F
2	2514.96	39750.1	
6	2514.39	39759.1	Near λ2514.33, Si I, but strong neighboring Si lines absent.
1	2508.45	39853.2	
12	2497.72*	40024.4	B I $2^2P_2-3^2S$*
10	2496.80*	40039.2	B I $2^2P_1-3^2S$*
2	2446.10	40869.0	
2	2445.11	40885.6	
1	2436.95	41022.4	
4	2434.95	41056.13	
5	2432.29	41101.0	B II 3^3S-4^3P
1	2430.82	41125.9	
1	2415.06	41394.3	

* Previously classified.

TABLE 1. *Continued.*

Intensity	Wave-lengths (In air)	Wave-numbers (In vaccum)	Classification
1	2400.03	41654.5	
3	2395.07	41739.7	
4	2369.96	42182.0	
3	2363.88	42290.5	B II 3^3P-5^3D
1	2363.51	42297.1	
2	2357.03	42413.3	
2	2355.25	42445.4	
	2267.0*	44097	B III $3^2P_2-4^2S$
	2266.4*	44109	B III $3^2P_1-4^2S$

* Given by Eder and Valenta, beyond the range of this work.

III. CLASSIFICATION OF LINES

BORON I

Rydberg[5] supposed the pair λλ2497.72, 2496.80 to be the first doublet of the sharp and principal series of B I. This view was confirmed by Popow's[6] observations of the Zeeman effect. The pair at λλ2089.80, 2088.90 given by Eder and Valenta[7] and a pair found by Millikan and Bowen[8] at λλ1826.41, 1825.87 have the same frequency difference as the doublet at λ2498 so probably belong to either the sharp or diffuse series of B I. Nothing has been found in the course of the present work to extend the knowledge of this spectrum.

BORON II

Millikan and Bowen[9] have classified several lines as arising from deep lying terms in the spectrum of B II. Their values are summaried in Table 2, page 293.

In the investigation herein reported two other pairs, λ2652.81 ($\nu = 37684.7$), λ2652.58 ($\nu = 37687.9$) and λ3136.85 ($\nu = 31870.0$), λ3136.64 ($\nu = 31872.1$), were found with the same frequency separation as the $3^3P_2P_{0,1}$ terms. The latter pair lies near the value of the 3^3P-4^3D lines as determined from Millikan and Bowen's terms, viz., $59006.5 - 28640.4 = 30366.1$ and $59010.0 - 28640.4 = 30369.6$. But since Milli-

[5] Fowler, loc. cit., p. 155.

[6] S. Popow, Archives des sciences phys. et. nat., *36*, p. 11; 1913.

[7] J. M. Eder and E. Valenta, Denkschr. Wien. Akad., *60*, p. 307; 1893; Beitrage zur Photochemie und Spectralanalyse, p. 82; 1904.

[8] R. A. Millikan and I. S. Bowen, Proc. Nat. Acad. Sci., *10*, p. 199; 1924; Phys. Rev., *24*, p. 209, 1924.

[9] I. S. Bowen and R. A. Millikan, Phys. Rev., *26*, p. 310; 1925.

kan and Bowen based these term values upon two independent estimates the differences are only approximations to the frequencies of the 3^3P–4^3D lines so the pair at λ3137 is used with Millikan and Bowen's

TABLE 2. *B II lines and terms by Millikan and Bowen.*

Int.	Wave-lengths (I. A., vac.)	Wave-numbers	Classification
1	4474.08	22351.0	$3^3P_2-4^3S$
1	4473.37	22354.5	$3^3P_{0,1}-4^3S$
6	4122.99	24254.2	3^3D-4^3F
2	2918.98	34258.5	3^3D-5^3F
3	1082.10	92412.8	$2^3P_2-3^3S$
3	1081.88	92432.1	$2^3P_{0,1}-3^3S$
3	882.69	113289.9	$2^3P_2-3^3D$
3	882.55	113308.2	$2^3P_{0,1}-3^3D$
0	731.46	136712.9	2^3P-4^3D
10	3452.33	28965.9	$2^1S-2^3P_1$
5	1842.83	54264.3	2^1P-3^1S
3	1378.95	72519.1	2^1P-3^1D
6	1362.46	73396.5	2^1S-2^1P

Term Values		Effective Quantum Number*
3^3S	72930.8	2.4513
4^3S	36655.5	3.4596
2^3P_2	165343.9	1.6289
$2^3P_{0,1}$	165362.7	
3^3P_2	59006.5	2.7268
$3^3P_{0,1}$	59010.0	
3^3D	52054.2	2.9031
4^3D	28640.4	3.9139
4^3F	27800.0	3.9726
5^3F	17795.7	4.9650
2^1S	194325.9	1.5026
3^1S	66665.1	2.5654
2^1P	120929.4	1.9047
3^1D	48410.3	3.0104

* The effective quantum numbers throughout this article are calculated with $N = NH_H$.

value of 4^3D to fix accurately the 3^3P levels and consequently the 4^3S levels as follows:

4^3D	28640.4	4^3D	28640.4
$3^3P_2-4^3D$	31870.0	$3^3P_{0,1}-4^3D$	31872.1
3^3P_2	60510.4	$3^3P_{0,1}$	60512.5
3^3P_2	60510.4	$3^3P_{0,1}$	60512.5
$3^3P_2-4^3S$	22351.6	$3^3P_{0,1}-4^3S$	22355.3
4^3S	38158.0	4^3S	38157.2

This gives an effective quantum number of 2.6927 for 3^3P_2 which is consistent with the number 1.6289 from Millikan and Bowen's value of 2^3P_2. In the case of the 4^3S term the effective quantum number comes out 3.3989 as compared with 2.4513 for their 3^3S term. This is unusual as the effective quantum numbers of the S series increase instead of decrease with the higher terms in the case of the Mg I, Al II and Si III atoms. Since these and B II are atoms of similar electronic configuration they might be expected to exhibit the same behavior in their series and no explanation of the difference is offered. The classification seems to be justified by the fact that this is the only pair found in this region. Further, if the other pair found to have the same frequency difference, λλ2652.81, 2652.58, is classified as 3^3P–5^3S it gives

	3^3P_2	60510.4		$3^3P_{0,1}$	60512.5
	$3^3P_2-5^3S$	37684.7		$3^3P_{0,1}-5^3S$	37687.9
	5^3S	22825.7		5^3S	22824.6
Mean	5^3S	22825.2			

The effective quantum number for this value is 4.3842 which checks well with that of 4^3S.

Since, as stated previously, the effective quantum number for the 2^3P_2 term as given by Millikan and Bowen is 1.6289 and for the 3^3P_2 term as worked out above is 2.6927 it is to be expected that the 4^3P term will have a quantum number slightly above 3.7 which would indicate the 4^3P term value to be approximately 32000. This would make 3^3S–4^3P and 3^3D–4^3P approximately as follows:

3^3S	72930.8	3^3D	52054.2
4^3P	32000	4^3P	32000
3^3S-4^3P	40930	3^3D-4^3P	20050

Taking the line λ2432.29 ($\nu=41101.0$) as 3^3S–4^3P and λ4940.87 ($\nu=20233.7$), as 3^3D–4^3P gives the following values for 4^3P:

3^3S	72930.8	3^3D	52054.2
3^3S-4^3P	41101.0	3^3D-4^3P	20233.7
4^3P	31829.8	4^3P	31820.5

The difference of nine units between these two values of 4^3P is rather large but does not seem inadmissible when it is considered that they were built up from the 2^3P_2 term by two independent paths. Each

path involved a line measured by Millikan and Bowen in the neighborhood of λ1000 where an error of one-tenth Angstrom, which is about the degree of accuracy of their work, would mean a frequency difference of ten units. Each path also involved one line reported here. An error of one-tenth Angstrom in λ2432.29 would cause two units difference in the frequency while λ4940.87 lay in the region where the uncertainty was between five-tenths and one Angstrom which would affect the frequency by two to four units. Taking $\nu = 31825.0$ as the value of 4^3P gives 3.7129 for the effective quantum number which is consistent with the numbers for the other ^3P terms.

Using 4.7 as the approximate quantum number for 5^3P indicates that it lies near $\nu = 19860$ which would make 3^3D–5^3P about $\nu = 32200$. λ3102.09 ($\nu = 32227.0$) comes very close to this.

3^3D	52054.2
3^3D-5^3P	32227.0
5^3P	19827.2

Effective quantum number—4.7040.

No other combination with 5^3P was found in the region of this work.

The first line, 3^3P–4^3D, of the second diffuse series has already been mentioned. λ2363.88 ($\nu = 42290.5$) was classified as the second member of this series. From this is obtained the value of 5^3D.

3^3P	60510.4
3^3P-5^3D	42290.5
5^3D	18219.9

Effective quantum number—4.9069.

Millikan and Bowen located the 5^3F term by identifying λ2918.15 as 3^3D–5^3F.

3^3D	52054.2
3^3D-5^3F	34258.3
5^3F	17795.7

The effective quantum number for this is 4.9650 while their assumed value of 4^3F would have 3.9726 as quantum number. This would indicate that 6^3F was near $\nu = 12330$ which would make 3^3D–6^3F, (52054–12330), about $\nu = 39720$. λ2515.06 ($\nu = 39748.5$) comes very close to this. Hence

3^3D	52054.2
3^3D-6^3F	39748.5
6^3F	12305.7

Effective quantum number—5.9706.

This completes all the lines of the triplet system of B II to be expected in the range covered by this work except combinations between higher terms.

In the singlet system of B II the 3^1D–4^1F line would be one of the most probable transitions in addition to those in Table 2. The 4^1F term would not be very far removed from the 4^3F so if 4^1F is tentatively assumed as being $\nu = 27800$ the 3^1D–4^1F line comes out $48400 - 27800 = 20600$. The line $\lambda 4849.6$ ($\nu = 20614.3$) is the only one found near this value and accordingly was given this classification. The intensity given is weak but the line occurs in a less sensitive region of the plate where no strong lines were observed. This identification gives

3^1D	48410.3
3^1D-4^1F	20614.3
4^1F	27796.0

Effective quantum number—3.9743.

This quantum number indicates that the 5^1F term is approximately $\nu = 17760$, hence 3^1D–5^1F would have a frequency of about 30650. $\lambda 3260.74$ ($\nu = 30659.1$) fits this almost exactly. The recorded intensity is greater than 3^1D–4^1F but that is to be expected since it is in a much more favorable region on the plate. From this

3^1D	48410.3
3^1D-5^1F	30659.1
5^1F	17751.2

Effective quantum number—4.9713.

The higher members of this series were not observed.

The only 4^1F–^1D lines in this region would be the higher members of the series, 8^1D or more. $\lambda 4761.4$ ($\nu = 20996.5$) is about the value to be expected for 4^1F–8^1D.

4^1F	27796.0
4^1F-8^1D	20996.5
8^1D	6799.5

Effective quantum number—8.0328.

This quantum number agrees well with that for 3^1D but the classification must be considered extremely doubtful without other evidence.

The ^1P and ^1S term values were built up from Millikan and Bowen's value of 3^1S ($\nu = 66665.1$) and 2^1P ($\nu = 120929.4$). The effective quantum number of the latter is 1.9047 from which 3^1P and 4^1P would have frequencies of approximately 51800 and 28700 respectively. In fact they would be expected to be less than these values in accordance with the ordinary behavior of P terms. 3^1S–3^1P would be of too low a frequency to be observed here but 3^1S–4^1P, approximately 38000, should be fairly strong. Accordingly $\lambda 2566.26$ ($\nu = 38955.5$), which is the most prominent line near the predicted frequency, was taken as the line sought. This determined 4^1P as follows:

3^1S	66665.1
3^1S-4^1P	38955.5
4^1P	27709.6

Effective quantum number—3.9790.

The 3^1P term was fixed by classifying $\lambda 4290.90$ ($\nu = 23298.6$) as the combination 3^1P–4^1P.

4^1P	27709.6
3^1P-4^1P	23298.6
3^1P	51008.2

Effective quantum number—2.9328.

Further evidence in support of this assignment lies in the coherence of the ^1S and ^1D terms calculated below which are based on this value of 3^1P.

The effective quantum numbers of the 2^1S and 3^1S terms are 1.5026 and 2.5654 respectively, from which would be predicted the approximate term values, 4^1S, $\nu = 34400$, 5^1S, $\nu = 21000$, and 6^1S, $\nu = 14100$. The 3^1P–4^1S line would be of too low frequency to be obtained here but $\lambda 3323.34$ ($\nu = 30081.6$) corresponds to the expected frequency of the 3^1P–5^1S line. This then locates the 5^1S term.

3^1P	51008.2
3^1P-5^1S	30081.6
5^1S	20926.6

Effective quantum number—4.5762.

The higher members of this series were not observed with any degree of certainty.

λ4214.17 ($\nu = 23722.8$) was classified as 3^1P–4^1D which gives 4^1D.

3^1P	51008.2
3^1P-4^1D	23722.8
4^1D	27285.4

Effective quantum number—4.0097.

This leads to approximate values of 17480 for 5^1D and 33528 for the term value of 3^1P–5^1D. This falls in a region where there are several iron lines in a very small range which makes positive identification very difficult. However, in measuring it was noted that one line, λ2981.53, of the group seemed to be very slightly displaced from the line of the comparison spectrum and its identification as an iron line questionable. The wave number of this line is 33530.0 and if it is classified as the one looked for 5^1D has the wave number 17478.2 with an effective quantum number of 5.0103.

The approximate value of 6^1D would be $\nu = 12150$, which would make 3^1P–6^1D about $\nu = 38850$. λ2566.40 ($\nu = 38953.4$) checks fairly well with this. This gives for 6^1D

3^1P	51008.2
3^1P-6^1D	38953.4
6^1D	12054.8

Effective quantum number—6.0323.

Any higher members of this series would be outside the range of this work.

The ^1P and ^1D terms found would indicate that the combination 3^1D–4^1P would have a value 48410.3–27709.6 = 20700.7. λ4829.0 ($\nu = 20702.7$) agrees with this.

This completes the classification of the lines found in this work which belong to B II. There should be strong $^3P'$, $^3D'$, and $^3F'$ terms in B II such as were found in Ca I, Mg I and Sr I by Russell and Saunders.[10] The first $^3P^3P'$ multiplet has been located by Millikan and Bowen[11] at λ1624. The $^3D^3D'$ and $^3D^3F'$ groups, however, should be of long wave length and might fall in the region here investigated. How-

[10] H. N. Russel and F. A. Saunders, Astrophys. J., *61*, p. 38; 1925.

[11] I. S. Bowen and R. A. Millikan, Phys. Rev., *26*, p. 150; 1925.

ever, to identify these would require sufficient resolution to observe their fine structure.

TABLE 3. *Series lines of B II.*

Classification	λ(I. A., air)	Int.	ν(vac).
3^3S-4^3P	2432.29	5	41101.0
$2^3P_2-3^3S$	1082.10* (vac)	3	92412.8*
$2^3P_{0,1}-3^3S$	1081.88* (")	3	92432.1*
$3^3P_2-4^3S$	4472.70	2	22351.6
	4472.83*	1	22351.0*
$3^3P_{0,1}-4^3S$	4471.97	2	22355.3
	4472.12*	1	22354.5*
$3^3P_2-5^3S$	2652.81	1	37684.7
$3^3P_{0,1}-5^3S$	2652.58	1	37687.9
$3^3P_2-4^3D$	3136.85	1	31870.0
$3^3P_{0,1}-4^3D$	3135.64	1	31872.1
3^3P-5^3D	2363.88	3	42290.5
3^3D-4^3P	4940.87	1	20233.7
3^3D-5^3P	3102.09	2	32227.0
3^3D-4^3F	4121.68	10	24254.8
	4121.61*	6	24254.2*
3^3D-5^3F	2918.15	1	34258.3
	2918.13*	2	34258.5*
3^3D-6^3F	2515.06	2	39748.5
			*
2^1S-2^1P	1362.46* (vac)	8	73396.5*
3^1S-4^1P	2566.26	3	38955.5
2^1P-3^1S	1842.83* (vac)	5	54264.3*
2^1P-3^1D	1378.95* (")	3	72519.1*
3^1P-5^1S	3323.34	3	30081.6
3^1P-4^1P	4290.90	0	23298.6
3^1P-4^1D	4214.17	0	23722.8
3^1P-5^1D	2981.53	1	33530.0 ?
3^1P-6^1D	2566.40	1	38953.4
3^1D-4^1P	4829.0	0	20702.2
3^1D-4^1F	4849.6	0	20614.3
3^1D-5^1F	3260.74	3	30659.1
$2^1S-2^3P_1$	3451.22	25	28966.0

* Observed by Millikan and Bowen.

TABLE 3. (*Continued*). *Series Terms of B II.*

Term Values		Effective Quantum Number
3^3S	72930.8*	2.4513
4^3S	38157.6	3.3989
	36655.5*	
5^3S	22825.2	4.3842
2^3P_2	165343.9*	1.6289
$2^3P_{0,1}$	165362.7*	
3^3P_2	60510.4	2.6927
	59006.5*	
$3^3P_{0,1}$	60512.5	
	59010.0*	
4^3P	31825.0	3.7129
5^3P	19827.2	4.7040
3^3D	52054.2*	2.9031
4^3D	28640.4*	3.9139
5^3D	18219.9	4.9069
4^3F	27800.0*	3.9726
5^3F	17795.7*	4.9650
6^3F	12305.7	5.9706
2^1S	194325.9*	1.5026
3^1S	66665.1*	2.5654
5^1S	20926.6	4.5762
2^1P	120929.4*	1.9047
3^1P	51008.2	2.9328
4^1P	27709.6	3.9790
3^1D	48410.3	3.0104
4^1D	27285.4	4.0097
5^1D	17478.2 ?	5.0103 ?
6^1D	12054.8	6.0323
4^1F	27796.0	3.9743
5^1F	17751.2	4.9713

* Determined by Millikan and Bowen.

BORON III

Treating B III as a hydrogenic atom Millikan and Bowen[12] identified eight lines of its spectrum and deduced the corresponding term values as given below.

[12] Millikan and Bowen, loc. cit.

TABLE 4. *B III lines and terms by Millikan and Bowen.*

Wave-lengths (I. A., vac.)	Wave-numbers	Classification
4499.0	22227	4^3F-5^3G
2077.79	48128	3^3D-4^3F
2066.41	48393	$2^3S-2^3P_2$
2067.88	48359	$2^3S-2^3P_1$
758.68	131808	$2^3P_2-3^3S$
758.47	131844	$2^3P_1-3^3S$
677.16	147676	$2^3P_2-3^3D$
677.01	147708	$2^3P_1-3^3D$

Term Values		Effective Quantum Numbers
2^3S	305938	1.7963
3^3S	125736	2.8019
2^3P_2	257545	1.9578
2^3P_1	257579	
3^3D	109870	2.9975
4^3F	61742	3.9966
5^3G	39515	4.9980

Rydberg's tables indicate the following approximate term values:

4^3S	68400	3^3P	112700	4^3D	61700
5^3S	42800	4^3P	62800	5^3D	39500
		5^3P	40100		

These approximations show that unfortunately the lines 3^3S–3^3P, $(125736-112700=13000)$, and 3^3P–3^3D, $(112700-109870=2830)$, have frequencies lower than could be observed in the present work. On the other hand 3^3S–4^3P, $(125736-62800=63000)$, and 3^3P–4^3D, $(112700-61700=51000)$, have frequencies which are too high to find here. Therefore no definite relationships can be established between the higher terms of the series and the lower terms which were obtained by Millikan and Bowen and any identification of isolated higher members of the series must be very questionable. However, it seemed desirable to attempt a tentative classification.

Eder and Valenta[13] reported a pair at λλ2267.0, 2266.4, ($\nu=44097$, $\nu=44109$) for which $\Delta\nu=12$. Although this pair has not been reported by any other observers it would seem to belong to the $3^3P_1{}^2P_2$ term inasmuch as the frequency separation, 12, is in about the same ratio to the $3^3P_1{}^2P_2$ separation, 31.4, of C IV as the $2^3P_1{}^2P_2$ separation of B III is to the corresponding separation of C IV, viz., 34.4 to 107.4.

[13] Eder and Valenta, loc. cit.

The identification of this pair as 3^2P–4^2S also gives consistent values of the terms 3^2P and 4^2S. Millikan and Bowen's 2^2S and 3^2S had quantum numbers of 1.7963 and 2.8019 respectively so 3.8050 was assumed for 4^2S by analogy with Li I, the 2^2S, 3^2S, and 4^2S terms of which have quantum number 1.588, 2.595 and 3.598 respectively. This makes $4^2S = 68184$ and

4^2S	68184	4^2S	68184
$3^2P_1-4^2S$	44097	$3^2P_1-4^2S$	44109
3^2P_2	112281	3^2P_1	112293

Effective quantum number for 3^2P—2.9650.

Of the lines arising from higher series terms, the approximate term values on page 19 indicate that 4^2S–5^2P, 4^2P–5^2S should be in the region studied. No lines have been found corresponding to these pairs.

For 4^2P–5^2D however:

4^2P	62800
5^2D	39519
4^2P-5^2D	23281

λ4311.9 ($\nu = 23185.2$) comes very close to this and if it is taken as the line sought it makes $4^2P = 62704$, effective quantum number 3.9677, in close agreement with 2^2P and 3^2P.

Also

4^2D	61758
5^2P	40100
4^2D-5^2P	21658

λ4677.9 ($\nu = 21371.2$) apparently corresponds to this and makes $5^2P = 40387$, quantum number 4.9436.

TABLE 5. *Series lines of B III.*

Classification	λ(I. A., air)	ν(vac.)
$2^2S-2^2P_2$	2065.75*	48393*
$2^2S-2^2P_1$	2067.22*	48359*
$2^2P_2-3^2S$	758.68* (vac.)	131808*
$2^2P_1-3^2S$	758.47* (")	131844*
$3^2P_2-4^2S$	2267.0**	44097
$3^2P_1-4^2S$	2266.4**	44109
$2^2P_2-3^2D$	677.16* (vac.)	147676*
$2^2P_1-3^2D$	677.01* (")	147708*
4^2P-5^2D	4311.9	23185
4^2D-5^2P	4677.9	21371
3^2D-4^2F	2077.11*	48128*
4^2F-5^2G	4497.7 *	22227*

* Observed by Millikan.

**Observed by Eder and Valenta.

Series terms of B III.

Term Values		Effective Quantum Number
2^2S	305938*	1.7963
3^2S	125736*	2.8019
4^2S	68184	3.8050
2^2P_2	257545*	1.9578
2^2P_1	257579*	
3^2P_2	112281	2.9650
3^2P_1	112293	
4^2P	62704	3.9677
5^2P	40387	4.9436
3^2D	109870*	2.9975
4^2D	61758	3.9975
5^2D	39519	4.9975
4^2F	61742*	3.9966
5^2G	39515*	4.9980

* Determined by Millikan.

IV. SUMMARY OF RESULTS

A glass spark-box more convenient to handle and adjust and subject to fewer insulation difficulties has been developed to replace the metal box previously used.

About one hundred new boron lines have been found in the region investigated and about twenty of these lines have been classified in series.

The experimental part of this work was carried out in the Physical Laboratory of the University of Michigan.

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OPTICAL CONSTANTS OF SINGLE CRYSTAL BISMUTH

By Florence E. Dix and Leroy H. Rowse

INTRODUCTION

Previous determinations[1] of the optical constants of bismuth have been made almost exclusively[2] for the polycrystalline metal. Since the bismuth crystal belongs to the rhombohedral class of the hexagonal system it is optically uniaxial and has two sets of optical constants. Results based on observations made on polished surfaces of the polycrystalline metal are therefore merely some sort of average of the actual crystal constants and are moreover liable to considerable variation depending on the method used to polish the reflecting surface. The work to be described is a determination of one of the two sets of characteristic optical constants of single crystal bismuth. By splitting a crystal along the natural cleavage plane perpendicular to the principal axis, which is also the optic axis in this type of crystal, a very fine reflecting surface is obtained without polishing. Monochromatic, plane polarized light of 45° azimuth reflected from this surface is transformed into elliptically polarized light. From the elements of this elliptical light the optical constants for light traveling parallel to the optic axis are obtained. The wavelength range is from 670 to 350 mμ.

PREPARATION OF CRYSTALS

The crystals used for the observations in the visible part of the spectrum were prepared as follows. The metal was heated in an open crucible to a temperature just above the melting point and allowed to undercool. A pair of tweezers inserted into the melt and withdrawn at just the right instant brought out a cluster of large crystals adhering to the tweezers. These crystals were split with a sharp knife and mounted on small pieces of plate glass. The reflecting surfaces obtained were several millimeters square. For the observations in the violet and ultraviolet somewhat larger crystals were desirable. They were prepared by the method of Obreimow and Schubnikow.[3] In this way it was possible

[1] Quincke: Pogg. Ann. Jblbd., *150*, p. 336, 1874.
Drude: Wied. Ann., *39*, p. 480; 1890.
Meier: Ann. d. Phys., *31*, p. 1017; 1910.
Also see Landolt-Börnstein Phys.—Chem. Tab. II, p. 906.

[2] Drude (loc. cit.) reports one observation on a rather poor cleavage surface.

[3] ZS f. Phys., *25*, p. 31; 1924

to obtain single crystal, cylindrical castings 2.5 cm in diameter and several centimeters in length. The cleavage plane generally made an angle of from 30 to 60 degrees with the axis of the cylinder, so that the reflecting surface obtained was elliptical and of several square centimeters area. Merck's C. P. bismuth was used for all the crystals.

EXPERIMENTAL PROCEDURE

In the visible region of the spectrum (670–470 mμ) a simple Stokes' analyzer[4] was used to determine the elements of the reflected elliptic light. Two incident angles were used, 69° and 73°. For each wave length and angle of incidence about ten readings were made, each one consisting of a direct and a complementary setting of compensator and analyzer.

In the violet and ultraviolet region (490–350 mμ) the crystelliptometer of Weld[5] was used. The "weaving" procedure was not necessary on account of the large size of the reflecting surface. The incident angles were 70 and 73 degrees. From three to six sets of photographs were taken at each wave length and angle of incidence.

Both methods analyze the elliptic light into two rectangular components from whose relative amplitude and phase difference the optical constants are obtained. These constants are: n, the index of refraction, nk, the extinction modulus, and R, the reflectivity. The formulas of Drude were applied in a similar fashion to that described by Tyndall[6] for molybdenite.

RESULTS

The values of the three constants are given in Table 1. At 490 and 470 mμ two sets are given since here the two methods of observation overlap.

In Figs. 1, 2 and 3 the three constants are plotted along with some of the previous determinations on polycrystalline bismuth for comparison. It will be seen that for the longer wave lengths the general trend of the constants is similar to that for polycrystalline metal, though the absolute values differ greatly as might be expected. It is interesting to note that the older values of Quincke are nearer the values here reported than the much more recent and presumably more accurate values of Meier. However, there is really no reliable basis for com-

[4] Phil. Mag., *2*, p. 420; 1851.
Skinner: J.O.S.A. and R.S.I., *10*, p. 495; 1925.
[5] See Meyer: J.O.S.A. and R.S.I., *13*, p. 557; 1926, for bibliography.
[6] Phys. Rev., *21*, pp. 172–174; 1923; p. 169 for definition of nk.

parison on account of the uncontrollable effect of polishing. In the violet region both the index of refraction and extinction modulus curves have maxima which are totally lacking in the polycrystalline material. This may be peculiar to the particular set of constants determined, in which case the other set of constants would show such a variation with wave length that the average of the two sets would show little variation, and thus give rise to the smooth curves obtained by

TABLE 1.

	n	nk	R
670 mμ	1.52	3.65	70.9%
650	1.46	3.71	70.8
630	1.42	3.60	70.2
610	1.37	3.52	69.5
589.3	1.35	3.36	67.8
570	1.28	3.27	67.8
550	1.24	3.17	67.0
530	1.19	3.03	66.0
510	1.18	2.93	64.7
490	1.13	2.88	64.9
490	1.11	2.94	66.0
470	1.04	2.74	64.3
470	1.10	2.87	65.1
460	1.25	3.41	69.8
450	1.28	3.38	69.1
440	1.17	3.30	69.8
430	1.09	3.01	67.5
410	.99	3.17	71.7
390	.93	3.00	70.6
370	.87	2.78	69.0
350	.82	2.57	67.1

Meier. It seems more likely, however, that the two sets of constants for bismuth are nearly the same as the crystal form is very nearly cubic and that the constants of the polycrystalline metal are only typical of the polished surface layer and depart largely from the constants of the material in the crystalline form.

Weigle[7] calls attention to a possible connection between the location of the photoelectric threshold for a metal and a sudden change in its

[7] Phys. Rev., (2), *25*, p. 893; 1925.

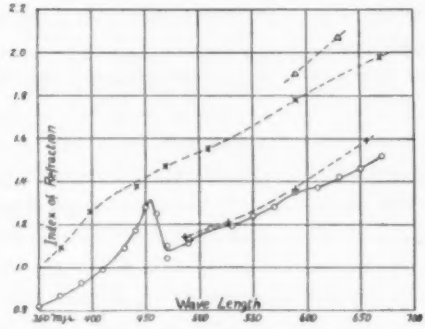

FIG. 1. *Index of refraction. O, Dix and Rowse; X, Meier; +, Quincke; Δ, Drude.*

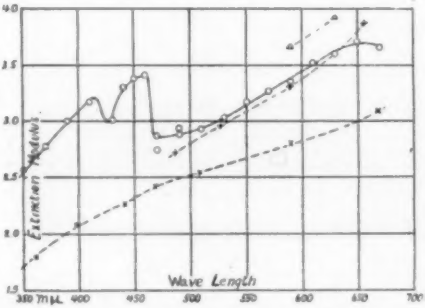

FIG. 2. *Extinction modulus. Symbols are the same as in Fig. 1.*

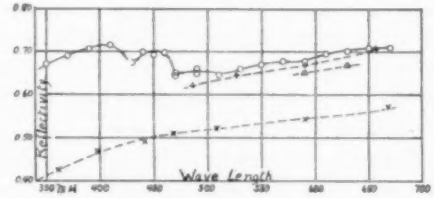

FIG. 3. *Computed reflectivity. Symbols are the same as in Fig. 1.*

coefficient of absorption. If this connection is real, then a surface prepared by the cleavage of a bismuth crystal should have its photoelectric threshold about 460 mμ.

The high reflecting power of the natural cleavage surface is worth noticing.

ACCURACY

Neither the visual nor the photographic method employed can be considered as precision methods. Some idea of the degree of accuracy attained, however, may be seen from the fact that although the visual readings were made by one observer (L.H.R.) while the photographic readings were made by another (F.E.D.) using different crystals and a totally different set-up, the agreement at wavelengths 490 mμ and 470 mμ is fairly good. Moreover, at just this region in the spectrum the accuracy of both methods is least. The deviation between individual sets of readings by one observer is in general less than that shown above between the two observers.

CONCLUSION

In conclusion the writers wish to thank Mr. G. P. Karch for preparing the large crystals employed for the photographic observations, and to express their appreciation to Dr. E. P. T. Tyndall for his advice and assistance during the progress of the work.

University of Iowa,
Iowa City, Iowa,
December, 1926.

PHOTOGRAPHIC REVERSION

By Vladimir P. Lubovich

The spectroscopist has to distinguish between true and photographic reversion. The true reversion of emission lines occurs frequently with a carbon arc and is due to the absorption of the radiation emitted by the central part of arc in passing through outer parts of it. As a rule not a particular line but several lines of the same series are reversed. An excellent exa mple of it may be found in the photograph of *D*-lines given in "The Study of Stellar Evolution" by G. E. Hale, (Plate XXII.).

The other, photographic reversion, finds its cause in the peculiarity of light action on sensitive emulsions. For each kind of emulsion at a given wave length and intensity there is a definite time of exposure for maximum density of developed image. If the time of exposure exceeds this interval the image loses in density and may become entirely undistinguishable from the general background. With still

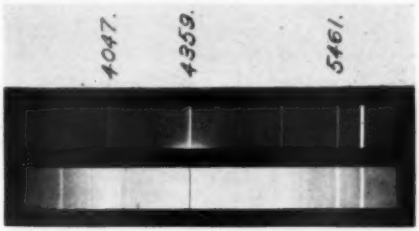

Fig. 1.

longer exposures the image may be nearly completely destroyed. This duration of exposure or a time even approximating it corresponds to complete reversion of a line. If the exposure is continued further the image gains in density again and after reaching a second maximum another reversion can take place. Although these facts are well known, the author takes the liberty of repeating them in view of the two new photographs which he hopes may present some interest. Fig. 1 gives two pictures of a mercury spectrum, the top one through Wratten filter No. 22 with 9 hours exposure, and the bottom one without filter and 20 minutes exposure. We notice that the line $\lambda = 4359$A on the bottom photograph is completely reversed. From the fact that of the other two lines $\lambda = 5461$A and $\lambda = 4046$A of the same series of triplets, the first is not reversed at all and the second is just beyond the stage of minimum density being hardly visible, we conclude that we are dealing with photographic reversion. The line $\lambda = 4359$A is the strongest line

in the region of high sensitivity of the plate and while the exposure was nearly correct for the other lines, the line happened to be very much overexposed. The filter reduced the intensity of illumination and the line $\lambda = 4359$A on the top photograph has its natural appearance. There are two faint lines to the left of $\lambda = 4359$A which appeared through the filter but are absent on the bottom photograph. Their absence the author ascribes to the duration of exposure corresponding to a minimum of intensity under the conditions of the photograph.

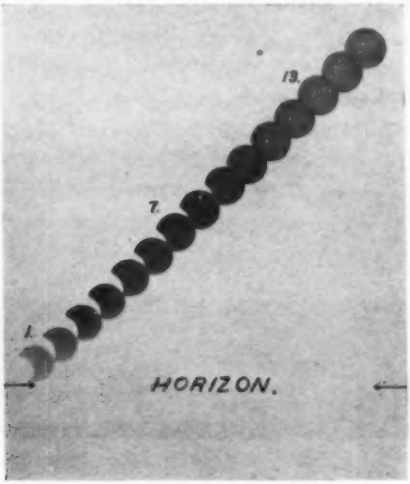

FIG. 2.

Another photograph, the positive of which is reproduced in Fig. 2 gives several stages of photographic reversion. The author attempted to photograph the solar disc during the eclipse of January 24, 1925, visible in Boulder as partial only. The first exposure was made at 7:21 A.M. (Mountain time), two minutes later another exposure followed and the last, the fifteenth, was made at 7:51 A.M. The intervals between exposures were in all cases two minutes. Each exposure was the same, one second. Since the exposure was far too long in every case all images are more or less reversed. Owing to the growing intensity of the rising sun the amount of reversion is increasing from the first to the seventh image. Further on the exposure was beyond the stage of maximum reversion and a gradual decrease of the reversion is observed up to the thirteenth image, after which the reverse

process begins again. The difference in density of the center and the edge of the solar disc is also in agreement with the above explanation.

In view of the possibility that the reproduction may not bring out clearly the variation of density, the author has measured photometrically the densities of the images on the original negative. The density of an image is defined as log I_0/I according to the usual custom where I_0 is the intensity of the light incident on the plate and I is the intensity of the transmitted light. The results of these measurements can be found in Table 1.

TABLE 1.

Image number	Density × 100	Image number	Density × 100	Image number	Density ×100
1	131	6	92	11	111
2	117	7	91	12	113
3	107	8	97	13	114
4	103	9	99	14	109
5	94	10	107	15	107

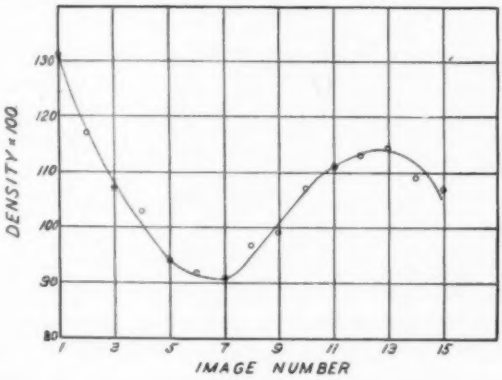

FIG. 3.

The variation in density is somewhat better perceived from the graph in Fig. 3. The graph suggests that the first image is beyond the first or perhaps even beyond the following maximum of density. The other feature of the graph is that the maximum corresponding to the thirteenth image is considerably lower than the one preceding it. This supports the idea that the process of repeated reversion due to overexposure is analogous in character to a damped vibration.

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THE LIGHT-SENSITIVENESS OF ZINC AND SILVER SALTS

By Ferdinand G. Brickwedde

Certain zinc and silver compounds have the property of darkening when exposed to ultraviolet light. In photography this property has proved very useful, but in the case of lithopone it is altogether undesirable and manufacturers make their product as light resisting as possible. Lithopone is a white paint pigment containing zinc-sulphide. Little is known about the photochemical change which takes place in lithopone; in the case of silver salts the change is better understood.

In brief the process for the manufacture of lithopone is as follows: Heavy spar ($BaSO_4$) is ignited with carbon and the mass dissolved in water making a solution of barium-sulphide (BaS). To this solution is added a solution of zinc-sulphate ($ZnSO_4$), and the white precipitate[1] of barium-sulphate ($BaSO_4$) and zinc-sulphide (ZnS) thus formed is washed, dried and ignited. After this it is mixed with 2 or 3 per cent of sal ammoniac, and again ignited. While hot it is thrown into water, and finally dried and ground. The ignition of the precipitate increases the hiding power of the pigment. The composition of lithopone in accordance with "Standard Specifications"[2] of the American Society for the Testing of Materials is as follows:

	Max per cent	Min per cent
Coarse Particles and Skins (total residue retained on a Standard No. 325 Screen)	1.0	
Zinc—Sulphide (Zn S)		26.0
Zinc—Oxide (Zn O)	2.0	
Materials Soluble in Water	0.8	
Barium—Sulphate ($Ba SO_4$)	(98% of the remainder)	

Like zinc-sulphide, lithopone phosphoresces when exposed to ultraviolet light in the absence of infrared radiation. The phosphorescent light of three or four samples of lithopones, manufactured by two different companies, was green like the phosphorescent light of zinc-sulphide; the light of the other sample, however, was brown. Besides exciting phosphorescence, ultraviolet light causes the surface of moistened lithopone to become gray and, if the light is intense enough,

[1] $BaS+ZnSO_4 \rightarrow BaSO_4+ZnS$.

[2] Page 66 of the "A.S.T.M. Standards Adopted 1926" by the American Society for the Testing of Materials.

to become black. Neither zinc-sulphide nor dry lithopone exhibits this light sensitive property. If lithopone darkened in this way is protected from the ultraviolet light, it bleaches and after a time becomes white. The presence of oxygen seems to quicken the bleaching. Manufacturers have developed processes for manufacturing lithopones of low light sensitivity. These "light-resisting" lithopones darken only after much longer exposures to light. It is interesting to note that the sample of lithopone which phosphoresced with a brown light was a "light-resisting" lithopone and turned brownish-gray in color instead of gray as the other samples.

In a paper entitled "Some Optical Properties of White Paint Pigments in the Ultraviolet Spectrum" presented at the Twenty-Sixth Annual Meeting of the American Society for Testing Materials, June, 1923, A. H. Pfund gave an account of some experiments on lithopone. Pfund found that different regions of the ultraviolet spectrum although of the same intensity required different times to darken lithopone to the same degree.

I. SENSITIVITY CURVES OF LITHOPONE AND SILVER-CHLORIDE

If each wave length of light to which the lithopone is exposed is of the same intensity, the sensitivities to the different wave lengths are inversely proportional to the times required to produce the same degree of darkening. The most convenient and, also, the most easily reproducible degree of darkening to choose is the first visible darkening of the exposed lithopone compared with unexposed lithopone. In this investigation the sensitivity curves of lithopone and silver-chloride as a function of wave length were determined by exposing samples to the more intense lines of a quartz-mercury-arc and noting the times each line, after being reduced to a common intensity, required to produce the first visible darkening of the exposed sample compared with an adjoining unexposed sample. The reciprocals of the times of first visible darkening, which are proportional to the sensitivities, were plotted against wave length.

The source of ultraviolet light used in this investigation was a "Cooper Hewitt" quartz mercury "Uviarc" operated at 110 volts. Homogeneous light, that is, light of a single frequency, was isolated by means of a quartz monochromator shown in Fig. 1. The mercury arc, collimator slit and lens were mounted on a movable arm which could be turned around the vertical axis of the prism table. The different lines of the mercury spectrum were isolated by varying the angle

of inclination of the collimator, the telescope lens and slit being stationary. As the collimator was turned, the collimator slit, mounted so as to slide along the axis of the collimator, moved along the line *MN* so that its image was in focus upon the telescope slit for all inclinations of the collimator after being focused for any one inclination. Between the cornu prism and the telescope lens was mounted a diaphragm of variable aperture by means of which the intensity of the light could be varied. A concave platinum plated mirror was mounted behind the telescope slit at a distance of its radius of curvature. This mirror could be turned about a vertical axis and thus the homogeneous light passing through the telescope slit could be reflected on the sensitive junction of a thermocouple or on a sample of lithopone, mounted on opposite sides of and close by the telescope slit so its image was in focus upon them. The energy of the light was measured with a sensitive

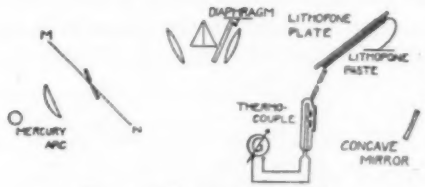

FIG. 1.—*Diagram of apparatus.*

thermocouple connected to a sensitive galvanometer. The energy was taken proportional to the galvanometer throw produced by a ten seconds exposure of the thermocouple to the light.

A little lithopone was made into a moderately thick paste with distilled water and a uniformly thin layer was pressed between a quartz plate, about the size of a spectacle lens, and a larger glass plate. Determinations of the sensitivity using pastes a little wetter and a little drier than the moderately thick pastes used, showed no differences in sensitivity due to the wetness or the dryness of the paste. Vaseline was smeared around the edges of the quartz plate to prevent drying of the paste, and the sample thus prepared was mounted at the side of the telescope slit with the quartz plate toward the mirror. As the telescope slit and its image were small, 2 by 10 mm, a number of determinations could be made on the same sample, the light being reflected each time on an unexposed part of the lithopone. From two different manufacturers were obtained a sample of their light-sensitive and a sample of their light-resisting lithopones. For convenience, the light-sensitive litho-

pones were marked lithopones *A* and *B*, and the light-resisting lithopones, *C* and *D*.

The lithopone plate was protected from the scattered ultraviolet radiation of the room and was illuminated by a 40-watt electric light placed about two feet away. The observer protected from the direct light, watched for the first appearance of a dark strip on the lithopone sample about fifteen inches away. By noting the position of phosphorescence when the electric light was momentarily turned off, the observer knew where the dark strip would appear. To eliminate the uncertainty in determining the *first visible* darkening, a number of determinations were made and the average taken.

Before determining the variation of light sensitivity with wave length, the relation of intensity to time of darkening was investigated. Two series of determinations were made of the times, different intensities of the lines 3126 and 2536A° required to produce the first visible darkening of lithopone *A*. To within the accuracy of the

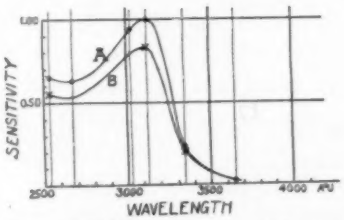

FIG. 2—*Light sensitiveness of lithopone.*

experiment, which was about 3 per cent, it was found that the time of first visible darkening is inversely proportional to the intensity of the light (reciprocity law). This can not be rigorously true, for during the time the dark substance is being formed the bleaching action is going on. For this reason lower intensities would be expected to require longer times than those calculated on the basis of the reciprocity law, but as the rate of bleaching is very slow as compared with the rate of darkening the difference is small.

Knowing that the time of first visible darkening is inversely proportional to the intensity of the light, it was not necessary to reduce all wave lengths accurately to the same intensity. What was done was to reduce the more intense lines of the mercury arc nearly to a common intensity; determine the times of first visible darkening; and, then, determine by calculation what the times of darkening would have

been had all the lines been of the same intensity. The sensitivity curve of the light-sensitive lithopone *A* (curve *A* of Fig. 2) was determined in two ways: First, the different lines were reduced to a common intensity and the sensitivities taken inversely proportional to the times of first visible darkening. Secondly, the intensities were varied until the times of darkening were the same for all the lines, and the sensitivities were taken inversely proportional to the intensities. The sensitivity of lithopone *A* to light of wave length 3126A° was arbitrarily taken as unity and the sensitivity to light of other wave lengths was compared with the sensitivity to 3126. The curves obtained by the two methods coincided. Times of darkening, using the first method, varied from half a minute to two minutes for the more sensitive lines, to sixteen minutes for the less sensitive lines. See Table 1.

TABLE 1.

Wave-length	Sensitivity of		Ratio of sensitiveness *B* to *A*
	Lithopone *A*	Lithopone *B*	
2536A°	.65	.55	.85
2654–2700	.63		
3024	.94		
3126	1.00	.83	.83
3342–52	.23	.20	.87
3650	.02		

The sensitivity curve (curve *B* of Fig. 2) of lithopone *B*, a light sensitive lithopone manufactured by a different company, was determined by comparison with *A*. Between the quartz and glass plates were pressed a sample of lithopone *A* paste, under the right half of the quartz plate, and a sample of lithopone *B* paste, under the left half, until the two met. The times required to produce the first visible darkening of the lithopone *B* paste were compared with the corresponding times for the lithopone *A* paste, a series of determinations being made alternately on *B* and *A*. The sensitivities of lithopone *B* compared with the sensitivity of *A* to 3126 are given in Table 1. It is interesting to note that to within the accuracy of the investigation the ratios of the sensitivities of *B* to *A* are constant.

The sensitivities of the light-resisting lithopones *C* and *D* were determined by another method better adapted to the determination of low sensitivities. Between the glass and quartz plates were pressed a sample of lithopone *A* paste, under the right half of the quartz plate, and a sample of light-resisting lithopone *C* or *D* under the left half. In this way the sensitivity of the light-resisting lithopones could be compared with the sensitivity of lithopone *A*. Two narrow strips of glass, a thick piece and a thin piece, were placed on the quartz plate across the two samples of lithopone as shown in Fig. 3, dividing the lithopone plate into three sections. The light in reaching the lithopone

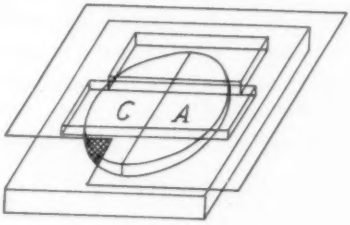

FIG. 3

of one section of the plate passed through the thick glass and quartz plates, in reaching another section passed through the thin glass and quartz plates, and in reaching the lithopone of the third section passed through only the quartz plate. For the transmission of the plates see Table 2. Over the plate was placed a piece of cardboard, one corner

TABLE 2.

Wave-length	Thick glass	Thin glass	Quartz plate
2536AU	—	—	0.83
2654–2700	—	0.00	0.83
3024	—	.42	.85
3126	0.00	.57	.86
3342–52	.20	.75	.89
3650	.80	.84	.92

of which had been cut away as shown in Fig. 3 so that one part of the plate could be exposed to the light and the other part of the plate protected from it. Thus prepared the different sections of the plate were exposed directly to the light of the mercury arc, and the times required to produce the first visible line of demarkation between the

exposed and unexposed parts were determined for a light resisting lithopone and for lithopone *A*. In this way the sensitivities of the lithopone to different regions of the spectrum were determined. The section of the plate under the thick glass strip was darkened principally by the region 3300 to 3700A°U, the section under the thin glass by the region 3000 to 3700, and the section under the quartz plate alone, by the region extending from the short wave length transmission of quartz to 3700. Before making a determination with a light-sensitive lithopone, the method was tested by a redetermination of the sensitivity of lithopone *B*. It was found that for the three sections, the ratios of the times of darkening of *B* to *A* were equal to the ratio previously found. The result of a number of determinations showed that the ratios of the times of first visible darkening of lithopone *A* to that of a light-resisting lithopone were the same for the three sections. At each wave length,

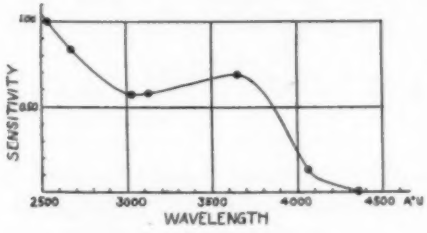

FIG. 4

then, the ratio of the sensitivity of the light-resisting lithopone to the sensitivity of *A* must be the same constant. The sensitivities of lithopones *C* and *D* were found to be very nearly the same and to be about 0.06 the sensitivity of *A*.

Except in the preparation of the silver-chloride plates and their illumination the sensitivity curve of silver-chloride was determined in the same way the sensitivity curve of lithopone *A* was determined. The silver-chloride plates were prepared by allowing a fine precipitate formed by mixing dilute solutions of silver-nitrate ($AgNO_3$) and hydrochloric acid (HCl)[3] to settle on glass plates which were afterwards left in a dark room to dry. During sensitivity determinations the plates were illuminated by a red photographic lamp. Silver-chloride darkens very much more rapidly than lithopone, though no attempt was made to obtain a quantitative ratio. The sensitivity curve of

[3] $AgNO_3+HCl \rightarrow AgCl+HNO_3$.

silver-chloride taking the sensitivity to radiation of wave length 2536 as 1.00 is shown in Fig. 4. Like the lithopone sensitivity curve the silver-chloride curve has a hump.

II. THE NATURE OF THE BLACK DEPOSIT

It is thought that the black substance formed when moistened lithopone is exposed to ultraviolet light is zinc.

The first experiment to test this was undertaken by A. H. Pfund, who found that lithopone darkened by exposure to ultraviolet light and lithopone on which zinc was distilled faded at the same rate. One part of a glass plate covered with lithopone paste was darkened by exposure to ultraviolet light, the other part being protected from the light. The plate was dried quickly, and zinc was distilled in vacuo on the unexposed part until the two parts matched in color. The plate was then immersed in water. As the lithopone bleached, the two parts of the plate remained matched in value, or grayness, showing that the rates of bleaching are the same.

An experiment was tried to determine how the photoelectric effect in this black substance compared with the effect in zinc. A zinc plate was connected with a negatively charged electroscope and the rates of leak of the charge were determined when various spectral filters were placed in the path of the light. Afterwards, the zinc plate was replaced by a lithopone plate darkened by exposure to ultraviolet light, and the rates of leak were determined for the same filters. To within a few per cent the ratio of the rates of leak were the same for all the filters. All parts of the apparatus connected with the electroscope were shielded from the scattered ultraviolet light of the room.

It seems probable that the photochemical change which takes place when moistened lithopone is exposed to ultraviolet light results in the liberation of metallic zinc, and hydrogen-sulphide. If then soluble salts, whose sulphides are insoluble, are present, sulphides will be formed, and if these are dark the light-sensitiveness of the lithopone should be increased. This was verified by comparing the times of first visible darkening of two samples of lithopone paste, one prepared with distilled water and the other with a lead-acetate solution containing ten grams of lead-acetate in a hundred grams of water. The sensitivity was increased 2.5 times by the addition of the lead acetate. If the sulphides formed are colored, the darkening will not be neutral in color, as in the case of the light-resisting lithopone which turned brownish-gray in

color when exposed to ultraviolet light. The brownish color was, probably, due to the formation of yellow ferric-sulphide.

In the making of light-resisting lithopones, manufacturers keep the chloride content of their product as low as possible. A comparison was made of the sensitivity of two samples of lithopone paste, one prepared with distilled water and the other with a solution of sodium-chloride containing ten grams of salt in a hundred grams of water. The sensitivity was increased 1.7 times by the addition of sodium-chloride.

In the making of lithopone pastes distilled water was used which had been in contact with the atmosphere long enough to become saturated with air. A comparison was made of the sensitivity of two samples of lithopone paste, one prepared with distilled water saturated with air, and the other with distilled water which was boiled, quickly cooled to room temperature and used. The times of first visible darkening were the same for the two pastes.

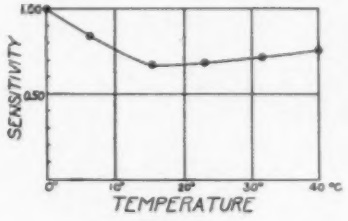

FIG. 5

The effect of temperature on the sensitivity of lithopone was also investigated. A thin layer of lithopone paste was pressed between the quartz plate and the outside of a flat sided, tin box filled with water. Determinations were made of the times of first visible darkening, the tin box being filled with water at different temperatures. The temperature-sensitivity curve taking the sensitivity at 0°C as 1.00 is shown in Fig. 5.

III. RELATIVE THERAPEUTIC VALUES OF VARIOUS ARCS

Ultraviolet therapeutic effects and the light sensitiveness of lithopone have long wave length limits near each other. Dr. Janet H. Clark[4] found that the darkening of lithopone is proportional to the physiological effects of ultraviolet light, and demonstrated that the darkening

[4] Amer. Journ. Physiology, *69*, No. 1, June 1924.

of lithopone can be used in clinical work to measure the amount of ultraviolet light administered to patients suffering with rickets. The relative therapeutic values of several arcs were determined by comparing the times of first visible darkening of lithopone plates exposed 40 cm from the arc to its light. With the exception of the Standard Pfund[5] and iron arcs, the arcs were struck between two vertical electric light carbons in the lower one of which was drilled a hole in which a bead of the metal was placed. Two iron rods were used as the electrodes of the iron arc. The arcs were operated at the currents which gave the most satisfactory operation. In Table 3 are given the (1) currents and potential differences between the electrodes of the arcs, (2) the times of first visible darkening, and (3) the therapeutic values of the arcs relative to the Standard Pfund Arc.

TABLE 3.

Type of arc	Current	Potential difference between electrodes	Time of first visible darkening	Therapeutic value relative to std. Pfund arc
Std. Pfund	5 Amp.	40 Volts	27 Sec.	1.0
Iron	6	55	28	1.0
Quartz mercury	4.7	36	4	6.8
Cadmium-carbon	10.	40	25	1.1
Copper-carbon	10	40	20	1.4
Aluminum-carbon	9	25	120	.2
Bismuth-carbon	8	30	45	.6
Carbon	5	55	600	.05

SUMMARY

(1) The light-sensitivity curves of the photochemical changes in lithopone and silver-chloride were determined. The sensitivities of the two substances do not increase regularly with decreasing wave length of the light.

(2) The time required for homogeneous light to darken lithopone to the same degree varies inversely as the intensity of the light.

(3) The ratio of the sensitivities of lithopones from different manufacturers are the same for all wave lengths.

(4) It was supposed that the photochemical change which takes place in lithopone results in the liberation of metallic zinc and hydrogen-

[5] Pfund, Astrophysical Journal, *27*, p. 296; 1908. St. John and Babcock, Astrophysical Journal, *46*, p. 138; 1917.

sulphide. This is supported by experiments which show that the rate of bleaching of light darkened lithopone and zinc distilled on lithopone are the same, by the similarity of the photoelectric effects, and by the increase in sensitivity upon the addition of soluble salts whose sulphides are black.

(5) The variation of sensitivity with temperature was also investigated. With increasing temperature the sensitivity decreases rapidly from 0° to 16°C, and then increases slightly from 16° to 40°C.

(6) The relative therapeutic values of several arcs were determined. Of the arcs tried the quartz-mercury arc had the highest value, being 6.8 times the value of the Pfund Iron Arc. The carbon arc had a value 0.05 that of the Pfund Arc.

In conclusion, the author wishes to express his thanks and deep appreciation to Professor Pfund who suggested the research and greatly assisted him in the course of investigation.

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Three Lectures on Atom Physics. By Arnold Sommerfeld. Translated by Henry L. Brose. 70 pages. E. P. Dutton and Company. New York.

The first two lectures deal with spectra. Lecture I discusses the quantum numbers n, k, j and m (magnetic quantum number), and the spectra of hydrogen and helium. Lecture II is devoted to "The General System of the Complex Terms." The third lecture takes up chemical bonds and crystal structures. Considerable attention is devoted to the periodic system of the elements and to the tetrahedral crystal structure of certain elements in the fourth group.

The book, while comprehensive, is very much condensed. It will best serve spectroscopists, quite familiar with the field, who wish an up-to-the-minute summary of very recent developments.

F. K. RICHTMYER

INSTRUMENT SECTION

A DIRECT CURRENT POTENTIAL TRANSFORMER

By Preston B. Carwile

A direct current potential transformer, operating electrostatically, has been devised, which so manipulates the connections of a direct current source and n condensers that the initial potential difference is multiplied by the factor 2^n. The device is simple in theory and operation. It embodies three essential principles, which will be treated in succession.

G. Planté employed[1] the first of the three principles in his "rheostatic machine," which consisted of a number of condensers and a commutator by means of which the condensers were first charged in parallel, then connected in series for discharge. Assuming that all stray capacity effects are small, it is obvious that if each of n condensers is charged to a voltage V, the total voltage between the outer terminals of these charged condensers when connected in series will be nV. This voltage nV is independent of both the absolute and the relative capacities. The potential transformation factor of such an arrangement is therefore equal to n.

We next bring into play what we shall call the *cumulative* principle. If we charge n condensers in parallel just as before, and then connect these charged condensers in series with one another and *also in series with the charging source*, we obtain a total (cumulative) voltage of $V+nV$, or $(1+n)\ V$. We see from this that the cumulative principle raises the transformation factor from n to $1+n$, which is not a large increase. We shall use this principle however, and a greater significance will appear in a later paragraph.

Now let us consider the third principle, which we shall designate as the *group* principle. In general, a group of x condensers may be used with a source of voltage V so as to give a voltage $(1+x)\ V$, as shown in the preceding paragraph. We may therefore use the original source with this group of condensers, as a source for charging a second group of x parallel condensers[2] to the voltage $(1+x)\ V$. If we now connect the

[1] G. Planté, Comptes Rendus, *85*, pp. 794–6; 1877.

[2] This cycle of connections will have to be repeated many times in order to charge the second group to the voltage $(1+x)\,V$, which is approached as an asymptote.

second group of charged condensers in series, the voltage across the group will be $x(1+x)V$. By connecting the original source, the first group and the second group, all in series, the total voltage will be

$$(1+x)V+x(1+x)V=(1+x)^2V \tag{1}$$

In the same manner we may use the original source with the first and the second groups of condensers, as a source for charging a third group of x condensers, and obtain a voltage $(1+x)^3V$. If we use y groups in this way the total voltage will be $(1+x)^yV$.

Let $n=xy$ be the total number of condensers. The transformation factor will be

$$T=(1+x)^y=(1+x)^{n/x}=\left\{(1+x)^{1/x}\right\}^n=F^n \tag{2}$$

where F stands for the function $(1+x)^{1/x}$.

The question naturally arises as to how to group a fixed number of condensers n so that the transformation factor T will have the largest possible value. We see from Eq. (2) that since n is constant T will be greatest when F is greatest, if we exclude negative values of F as not applicable to our problem. Let us therefore find the greatest value of the function F. Since we are interested in only *positive integral* values of x we shall not regard negative values; we shall, however, consider x as a continuous variable for the purpose of studying the behavior[3] of F. By differentiating and rearranging, we have

$$\frac{dF}{dx}=\frac{d}{dx}(1+x)^{1/x}=\frac{(1+x)^{1/x}}{x^2(1+x)}\left[x-x\log_e(1+x)-\log_e(1+x)\right] \tag{3}$$

which is negative[4] for positive values of x. This means that F grows larger as x is made smaller, and therefore the greatest available value of F is given by putting $x=1$, the smallest positive integer. This gives

$$F=(1+1)^{1/1}=2 \tag{4}$$

From equations (2) and (4), the greatest available transformation factor is thus found to be

$$T=2^n$$

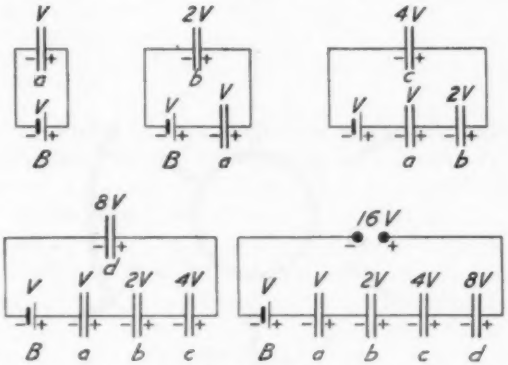
[3] It is worthy of notice that $\underset{x=0}{\text{Lim}}\, F=\underset{x=0}{\text{Lim}}\,(1+x)^{1/x}=\underset{z=\infty}{\text{Lim}}\,(1+1/z)^z=$ Napierian base, e.

[4] The expression in brackets is 0 when $x=0$. Its derivative is $-(1+x)$, which is negative for positive values of x. The factor in brackets is therefore negative when x is positive. The factor in front of the brackets is positive for positive values of F and x. Hence the product of the two factors is negative when x is positive.

By way of illustration, Planté's "rheostatic machine" used thirty condensers and gave a transformation factor of 30, whereas thirty condensers used in the manner just indicated, would give theoretically a transformation factor of 2^{30}, which is more than 1,000,000,000.

It can be shown that if we had applied the *group* principle without the *cumulative* principle (which did not seem promising in itself) we could obtain a transformation factor of not more than $(3)^{n/3} = (1.44 \cdots)^n$ as against 2^n.

We have seen that in order to have the largest possible transformation factor we must have $x = 1$. This means that the n condensers are to be arranged in n groups of one each. Figs. 1 to 5 show a possible sequence



FIGS. 1–5. *Connections showing the application of the cumulative and group principles to four condensers.*

through a cycle of connections for such an arrangement in which $n = 4$. The voltages indicated are the values attained after many cycles. Obviously the scheme is applicable to any number of condensers.

A convenient mechanical device for making connections in such a sequence is shown in Fig. 6. The heavy lines represent metal segments fixed to a rotating disc of insulating material. As these segments pass the stationary brushes (indicated by small circles) they make connection between the battery and the condensers. The battery and the condensers are stationary, being connected to the brush terminals in the rear. The position of the commutator segments shown in the figure, gives the connections indicated in Fig. 1. The connections of Fig. 2 will be made by rotating the commutating segments sixty degrees clockwise. A rotation of sixty degrees further still, will make the connections of Fig. 3, and so on through the cycle.

A rough model was constructed, using 4 condensers of which the largest had a capacity of two microfarads. Voltages up to 110 were applied to the primary[5] at O and V (Fig. 6). An electrostatic voltmeter and a storage condenser were connected in parallel across the secondary at O and $16V$, the storage condenser being used to maintain a steady deflection of the voltmeter since the machine discharges only once each revolution. After the storage condenser becomes well charged, the electrostatic voltmeter indicates a secondary voltage 16 times as great as the primary voltage, thus verifying the theoretical transformation factor 2^4. With 100 volts across the primary, a speed of about five

FIG. 6. *Diagram of a direct current potential transformer using four condensers.*

revolutions per second, and with the secondary terminals short-circuited through a galvanometer, the average current delivered is of the order of one-tenth milliampere. The operation is found to be independent of the direction of rotation of the commutator.

We see that such an instrument constitutes essentially a direct current potential transformer whose transformation factor does not depend on the absolute capacities, the relative capacities, the direction or speed of rotation, but depends only on the number of condensers used. We see further that no great number of condensers is required in order to obtain a high voltage from a low voltage source, since the trans-

[5] Clearly such a device is a transformer rather than a generator, since no work is done on the charges coming from the original source.

formation factor 2^n increases rapidly as the number of condensers n increases.

Two questions which are relative to such a device but which have not been worked out are:

1. General quantitive theory of actual operation, taking into account the current and voltage relations as affected by absolute capacities, relative capacities, stray capacities, contact potentials, leakage, etc.
2. Investigation of its use for *maintaining* and *measuring* high potentials, for work in which high potentials but only small currents are required.

ROUSS PHYSICAL LABORATORY,
UNIVERSITY OF VIRGINIA,
UNIVERSITY, VA.
DECEMBER 2, 1926.

Reports of the Physical and Technical Roentgen Institute and The Leningrad Physical and Technical Laboratory 1918–1926; Scientific and Technical Publishing Office, Leningrad, U. S. S. R., 1926, 232 pages, price $3.00.

The purpose of this publication is stated in the introduction. The organization period of these laboratories under the direction of Prof. Joffe is completed, and a collection of the papers published by their staffs seemed the best means to outline what has been accomplished and to indicate the scope and purpose of the work now in progress. The original papers were published in German and Russian and, with the hope of broadening their contact with the scientific world, this publication has been written in English.

The thirty papers in this volume are chiefly devoted to pure physics, with some brief notes on technical applications. Among the subjects treated are, electron theory, x-ray spectroscopy, ionization of salt vapors, and the mechanical and electrical properties of dielectric crystals. The work on the last subject is the outstanding accomplishment of these laboratories. Prof. Joffe and his colleagues have opened up a field of research that is of fundamental importance. There is no doubt that this publication will do much to stimulate the interest of English and American physicists in the scientific work of Russia. There are fields of research where they are far ahead of us, and closer cooperation will certainly result in mutual advantages. In fact this publication cites at least one instance where laborious computations were duplicated by several physicists in different parts of the world.

F. L. MOHLER

KIRCHHOFF'S BRIDGE

By M. N. States

In order that, early in their course, students of electricity may become familiar with Kirchhoff's Laws for electrical circuits, a piece of apparatus has been designed which makes possible the experimental verification of these laws for steady currents. While it is true that many laboratory excercises included in elementary courses in electricity quite satisfactorily demonstrate Kirchhoff's Laws, one experiment which makes them the central idea is not entirely out of place in such a course. Having mastered such an experiment, students have a clearer conception of these laws and appreciate to a greater extent their wide range of usefulness than generally results from the treatment given

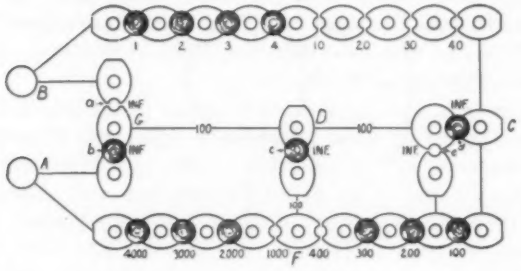


FIG. 1. *Top view of Kirchhoff's bridge.*

this subject in the average college text. In the strictest sense of the word, the apparatus is not a bridge, but for want of a better nomenclature it has been called "Kirchhoff's Bridge."[1]

In designing the bridge, care was taken to make the apparatus as flexible as possible, from the standpoint of utility. Reference to Fig.1, which shows in detail the resistances and connections, reveals that the bridge is primarily an ordinary resistance box. The bridge may be used, therefore, wherever such a resistance is needed. With the addition of the three 100 ohm coils and auxiliary connections a considerable

[1] The circuit used in the experiment (Fig. 2) is, in form, the same as a Wheatstone bridge, where r_6 corresponds to the resistance of the galvanometer and r_1 a resistance in the mesh containing the emf.

variety of three mesh circuits (Fig. 2) is made possible. The laboratory exercise involves the theoretical and experimental analysis of such a circuit.

For the circuit schematically shown in Fig. 2, the following equations automatically satisfy both of Kirchhoff's relations. In writing the equations the internal resistance of the battery is assumed to be a negligible quantity in comparison to the other resistances of the circuit.

$$\begin{aligned} i_1r_1+(i_1-i_3)r_5+(i_1-i_2)r_4&=E \\ i_2r_2-(i_1-i_2)r_4-(i_3-i_2)r_6&=0 \\ i_3r_3+(i_3-i_2)r_6-(i_1-i_3)r_5&=0 \end{aligned} \qquad (1)$$

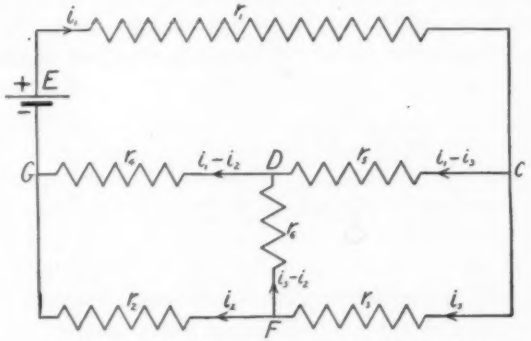


FIG. 2. *Schematic diagram of net-work of three meshes.*

Since the emf in two of the meshes is equal to zero, the solution of these equations for the currents offers the student a simple yet excellent exercise in determinants. Assuming values of r_1, r_4, r_5, and r_6 to be equal to 100 ohms each, $r_3=400$ ohms, and r_2 equal to 1000 ohms, (See Fig. 1 for actual bridge connections), the above expressions for the currents reduce to:

$$\begin{aligned} i_1&=3.68\ E \text{ ma} \\ i_2&=\ .36\ E \text{ ma} \\ i_3&=\ .67\ E \text{ ma} \end{aligned} \qquad (2)$$

Using a battery of 9 or 10 volts emf it appears from Eq (2) that these currents as well as (i_1-i_2), (i_1-i_3) and (i_3-i_2) are of the order of a few milliamperes, and that the drops in potential across the various resistances are a volt or two. The computed values of the currents

(i_1-i_2), (i_1-i_3) and (i_3-i_2), the interpretations of which usually offer the beginner difficulty, are checked by inserting a milliammeter of negligible resistance in the circuit at the proper places. Traveling plugs attached to the milliammeter and the infinity plugs b, c, and d(Fig. 1) facilitate making these observations. To avoid the introduction of a fourth mesh, the drops in potential across the various resistances are verified by the condenser and discharge key method. With a milliammeter of range 0 to 50 ma and a ballistic galvanometer of approximately 50 megohms sensitivity, the student can compare computed and observed values of the currents and potential drops across the resistances to within 1.5 per cent or less.

The resistances r_4, r_5, and r_6 have fixed values of 100 ohms each. The resistances r_1, r_2, and r_3 may take on various values. In fact, in all, there are 240 different circuits available in which all of the resistances

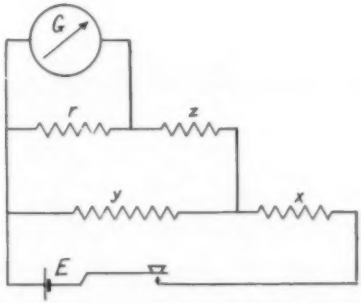


FIG. 3. *Bridge connection for figure of merit determination.*

are multiples of 100 ohms. Of this large number, more than 100 are suitable for laboratory exercises. Hence, in large laboratory sections repetition of assignments is made unnecessary. Furthermore, the general solutions of Eq (1) furnish the instructor a quick check on the student's work.

By an arrangement of the bridge as in Fig. 3, the figure of merit of a galvanometer may be quickly obtained. All of the plugs are removed from the bridge except two. These plugs are at points in the circuit, (a and c, Fig. 1, or in mesh, y, Fig. 3), where contact resistance of the plugs would be of negligible significance. It is obvious, therefore, that extraneous resistance is practically eliminated, for the values of $x=10{,}000$ ohms, $y=200$ ohms, $r+z=1{,}110$ ohms, and $r=1, 2, 3\cdots$ depending upon the resistance and sensitivity of the galvanometer.

With this arrangement the figure of merit, F, is given by

$$F=\frac{rE10^{-7}}{\phi[(G+r)13.322-.0102r^2]}\text{amp} \qquad (3)$$

where r is the resistance across which the galvanometer of resistance G is shunted to produce a deflection of ϕ radians. The emf in the circuit is E. Without appreciable error the last term in the denominator may be neglected and Eq. (3) reduces to the simple and convenient form

$$F=\frac{rE(7.5)\cdot 10^{-9}}{\phi(G+r)}\text{amp} \qquad (4)$$

The bridge will also satisfactorily demonstrate the principle recently announced by Dr. Wenner,[2] of the Bureau of Standards, in a paper entitled, "A Principle Governing the Distribution of Current in Systems of Linear Conductors." To do this it is merely necessary to insert a milliammeter and an electromotive force of from 1.5 to 2 volts in a branch of the bridge, as for example DF (Fig. 2), in such a way as to oppose the current in that branch, and to apply a variable potential to the bridge by means of a battery and slide wire rheostat, used as a potentiometer instead of the constant electromotive force E. By varying the potential applied to the bridge the current in the branch DF may be reduced to zero as indicated by the milliammeter. Then, according to the principle announced by Dr. Wenner, the current strength in the branch DF will be the same magnitude with either electromotive force removed from the circuit, but all resistances remaining the same. The two currents will be found to be as nearly the same, as one can judge two readings of the instrument, the currents of course being oppositely directed.

In conclusion,[3] it may be stated that, after two year's trial in laboratory sections of college physics at the University of Kentucky, this apparatus seems to have worth-while instructional value from the point of view of both teacher and student. It has further demonstrated its general usefulness in the rapid determination of the figure of merit of galvanometers as well as its obvious use as a resistance box.

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[2] Wenner; Bureau of Standards Scientific Paper, No. 531, July 16, 1926.

[3] A more complete description of this apparatus may be found in Cumulative Unit Experiments No. E-10, published by the Central Scientific Company.

A COMPARISON OF THREE SPECTROPHOTOMETRIC METHODS

By Lauriston Taylor

At the outset of an investigation of the specific exciting power of fluorescence in regions where Stokes law is violated, considerable difficulty was encountered in choosing the best method by which to make spectrophotometric measurements.[1] There seemed to be little information in the literature giving even a rough comparison of the relative sensitivities of the common methods, and for that reason it seemed of interest to make such a comparison of some methods actually tried.

The three methods herein studied were those which used respectively: I. The ordinary Lummer-Brodhun spectrophotometer. II. A spectrograph in which the fluorescence and comparison spectra were photographed simultaneously by means of a divided slit. III. A photo-electric spectrophotometer.

I. The first method was found to be totally inadequate for the intensities of light under investigation. The field of view was so faint that it could be seen only after the observer had been dark adapted for a few minutes. At such weak intensities the error in observation was as high as 15 or 20 per cent.

II. The second method seemed capable of considerably more accurate results but was both cumbersome and slow. The eyepiece of the telescope on a large spectroscope was replaced by a divided slit such that the fluorescent light entered the upper half of the slit. Light from a standard comparison source on a photometer track entered the lower half slit after internal reflection from a small 45° prism. This gave the two spectra, one above the other and so close together as to minimize the effect of irregularities in the plate emulsion. The exposed plate was then run through a photo-electric comparator[2] and match points of blackening were obtained between the two bands. This method required a new setting of the photometer track for every pair of points, and consequently another exposure. For moderately strong light intensities this method is very useful. However for the

[1] E. H. Kennard, Phys. Rev. *29*, p. 466, 1927.
[2] J. O. Perrine, Phys. Rev., *22*, p. 48, 1923.

fluorescence intensities available, the exposures varied from 2 to 20 hours, thus making a very slow procedure.

III. The third method employed the same spectrometer as in II but substituted a photoelectric cell for the eye or the photographic plate. Light from the fluorescence cell was focused directly onto the collimator slit by means of a small cylindrical lens. Light from the comparison source was diffusely reflected from a magnesium carbonate block which could be moved into position before the same slit when desired (Fig. 1).

The spectrometer was one of large aperture and high dispersion, and so constructed that either a photographic plate holder or a photoelectric cell could be attached to the telescope slit.* The photoelectric cell was contained in an hermetically sealed metal box containing

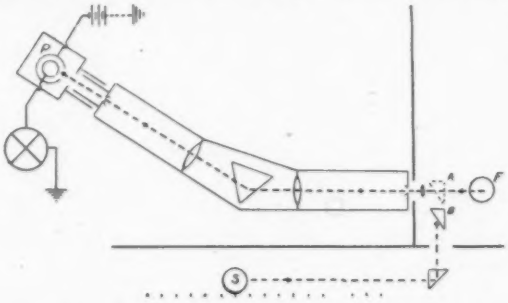

FIG. 1 *Diagram of photo-electric spectrophotometer. F, fluorescence cell. S, standard comparison lamp. B, Magnesium carbonate block. P, photo-electric cell.*

phosphorus pentoxide. This box was suspended directly beneath a specially constructed Compton electrometer of high sensitivity (20,000 to 25,000 mm/volt at 1.5 m scale distance). The quadrants and suspended system were made slightly smaller than the specifications given by Compton,[3] in order to reduce the capacity of the system.

In making comparison observations the rate of drift of the electrometer was taken over the same part of the scale for both sources of light. After an initial drift due to the fluorescence, the comparison light was adjusted along the track by a few trials to give a rate of deflection approximately the same as that given by the fluorescence light. In taking working data, the comparison light intensity was ad-

* The telescope system was built by the author in this laboratory, being of larger aperture than is ordinarily obtainable, and more adapted to the particular problem.

[3] A. H. Compton, Phys. Rev., *14*, p. 85; 1919.

justed more closely to that of the fluorescence light, alternate readings being taken by shifting the magnesium block in and out (i. e. position *A* and *B* in Fig. 1). By this method a spectrophotometric comparison could be taken in a few minutes as compared to several hours by the photographic method.

SENSITIVITY COMPARISONS

It is of course obvious that no precise comparisons can be made of the sensitivity of the three methods described above. It seems of some interest however to give even an approximate estimate of the relative sensitivities and the precision of each method.

A. *Photoelectric vs. Photographic Method.* The sensitivity of the photoelectric method can be pushed beyond certain limits only at the expense of precision. Down to a certain low intensity of light, the error in observations may be reduced to about 1 per cent, a lower limit well below the range of the visual spectrophotometer. The conditions of observation for such accuracy are: an electrometer sensitivity of 8,000 mm/volt and a potential applied to the photoelectric cell 5 or 6 volts lower than that at which the blue glow discharge occurs.

By increasing the cell voltage to 1 volt below the blue glow potential, the sensitivity may be increased by a factor of about 10. However there now appear certain irregularities in the electrometer drifts, the magnitude of which increases with increase in applied cell voltage. By further increasing the electrometer sensitivity to 25,000 mm/volt a factor of 3 may be gained. However while greatly increasing the sensitivity by these means, the error of observation is also increased. In spite of the increased error the method is still of great value since it is measuring light which is too weak to measure by other means.

In the comparisons below, the slit widths were adjusted to pass a spectral band 40Å wide in the green region. This was about the slit width used in the fluorescence study.

To compare the two methods, the potential on the cell was fixed at 3.0 volts below maximum and the sensitivity of the electrometer was adjusted to about 20,000 mm/volt. The comparison light was then set on the track to give a net rate of drift of about .36 cm/sec at a wave length of 5230Å. In practice a rate of drift of 0.1 cm/sec can be easily used. For a set of 10 observations the average deviation of a single observation from the mean was 4.2 per cent.

Within reasonable limits, this deviation does not depend upon the intensity of light. Thus the incident light may have an intensity

20 or 30 per cent of that above, and still be measured with the above precision.

Next the photographic attachment replaced the photoelectric cell and the same light was photographed on three different plates, viz.: (1) Ilford Special Rapid Panchromatic, (2) Eastman Astronomical Green Sensitive and (3) Eastman D-C Ortho. Exposures of 16 hours failed to produce any image on plate 1. An 8-hour exposure of plate 2 gave an image, but it was too faint to be of any use and was no greater than the blackening due to irregularities in the emulsion. Sixteen hours on the same plate gave a faint but measurable blackening through the errors in measurement by the comparator are large. A 24-hour exposure of plate 3 gave a blackening of approximately the same density as the 16-hour exposure of plate 2. Table 1 summarizes the information above.

Table 1.

Plate	Exposure (hr.)	Image
1	16	none
2	8	very faint
2	16	faint (measurable)
3	24	faint (measurable)

B. *Spectrophotometric vs. Photoelectric Method.* In order to obtain some idea of the merit of the spectrophotometer for faint light, a set of intensity matches was made with a moderately bright field. At two wave lengths—5200Å and 4700Å—, the average deviation of a single observation from the mean was 4.4 and 3.4 per cent respectively. The intensity of both light sources was then lowered equally until the field was just visible with slight dark adaptation. The corresponding errors in readings were now 18.5 and 14.5 per cent respectively.

Next the light from one collimator only was directed through the instrument. The light leaving the telescope slit passed through a .25 transmission neutral filter before entering the photoelectric cell. The cell voltage was 3 volts below maximum and the electrometer sensitivity was set at about 20,000 mm/volt. The rate of drift was of the order of 1.0 cm/sec.

By using the light through only one entrance slit, the data is made comparable to that, had the instrument been used simply as a spectrometer in method III above.

For a series of observations using the photoelectric cell, the deviation of a reading from the mean for the two wave lengths was 1.8 and 2.8 per cent respectively. Thus it is apparent that the photoelectric

method is considerably more accurate at intensities which are too low for easy visual observations.

However its sensitivity can be pushed further. Removing the filter adds a factor 4; using a slower rate of drift adds a factor 10 and increasing the cell potential adds a factor of about 5. Thereby in all, a factor is gained which makes it possible to measure light intensities which are 1/200 of those measured easily with the spectrophotometer.

With the particular cell used* the maximum sensitivity occurred at 4500Å wave length of the incident light. This fell off to 50 per cent at wave lengths 4000Å and 4750Å, and to 17 per cent at 5200Å. Thus, knowing the sensitivity curve of the cell used, one is enabled to determine in advance the relative sensitivity of the method at different wave lengths.

For the D-C Ortho Plate used** the maximum sensitivity occurred at about 4800Å and for the Astronomical Green Sensitive plate at about 5600Å. Thus, also, a knowledge of the spectral sensitivity of the photographic plate is of value in comparing and choosing the method to be used in making observations.

SUMMARY

By way of summary, the Table 2 below is given, showing the precision attainable for the several relative intensities shown in column 2. The unit of intensity is perfectly arbitrary. The intensity marked 1 is such that an observer is able to see it only after a few minutes dark adaptation. The error given for the photographic method has little real meaning since it depends upon the method of measuring the blackening, the quality of the plate, and other factors.

Table 2.

Method	Relative intensity	Per cent error	Time of single observation
Spectrophotometric	10	4	1–2 min.
"	1	14–18	1–2 min.
Photographic	.005	5–25	2–20 hr.
Photo-electric	.005	2–6	3–5 min.

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*Kunz type cell—made by Central Scientific Company.

**Wedge spectrograms for the various plates were kindly furnished through Mr. L. A. Jones of the Eastman Kodak Company.

AN INFRARED SPECTROMETER OF LARGE APERTURE

A. H. PFUND

The usual mirror spectrometer for infrared work makes use of concave reflectors having a comparatively small aperture. Even though reflection takes place off the optic axis of the concave mirrors, it is possible to produce a sharp spectrum in the position of the primary focal line. If, however, the aperture be increased greatly the slit image suffers

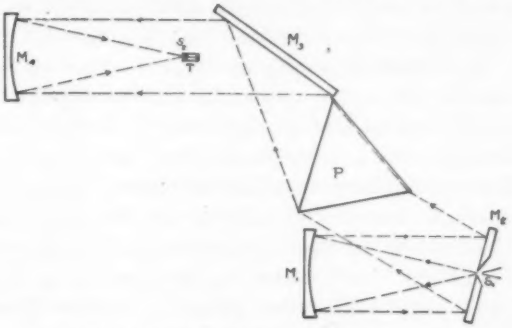

FIG. 1. *Complete prism-mirror spectrometer.*

from the various aberrations to such an extent that the resultant spectrum becomes very impure. These defects have been overcome in the arrangement shown in Fig. 1.

Radiation from the slit S_1 is allowed to fall on the concave (paraboloidal) mirror M_1 from which parallel rays are reflected *along the optic axis* to the pierced plane mirror M_2. The radiations, after passing

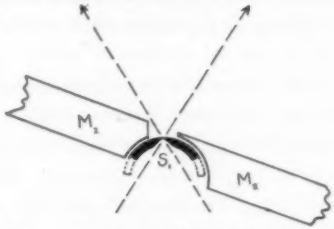

FIG. 2. *A more detailed drawing of slit S.*

through the Wadsworth prism-mirror arrangement PM_3, are again *reflected along the optic axis* of the paraboloidal mirror M_4 and are brought to a focus at a second slit S_2 and thermopile T. A more detailed drawing of the pierced mirror M_2 and slit S_1 is shown in Fig. 2.

The opening in M_2 is about 8x15 mm on the reflecting side of the mirror, the glass being cut away sufficiently on the other side to make room for the slit. This is of the bilaterally symmetrical type and is made of cylindrical form so as to move along the dotted lines when widened. As a result the change in position of the centre of the slit, upon changing its width, is very slight.

If a thermopile is used, it is mounted back of S_2 in a small rectangular box. The dimensions of this box, in a plane perpendicular to the direction of the direction of radiation, are again 8x15 mm while the third dimension (parallel to the radiation) may be chosen as large as may be desired. This simply means that the box lies within the non-luminous area occasioned by the hole in mirror M_2. The thermopile is so constructed that the receiving areas are perpendicular to the plane of the wires—thus making it possible to separate the "hot" and "cold" junctions by any desired amount without an additional cutting down of the effective area of the concave mirrors. The jaws of the slit S_2 are made of razor blades which are mounted on a rigid support presenting a minimum of area to the radiation. The area lost by the opening in m_2 and the slit supports is only about 2.5% when concave mirrors of 10 cm diameter are used.

Should it become necessary to use a non-portable instrument such as a radiometer or radiomicrometer, it is only necessary to remove the thermopile and to mount a small, plane mirror which reflects the radiation to an additional concave mirror which in turn, finally brings the slit image of S_2 to a focus on the blackened receiving area of the instrument in question. In general, it may be stated that this spectrometer design is applicable to apertures of any size, to prisms, echelette and wire gratings and to portable as well as non-portable receiving instruments.

A spectrometer of this type has been constructed and used in conjunction with a coarse echelette grating—the latter replacing the Wadsworth mirror and prism system. Concave mirrors of 10 cm diameter and 20 cm focal length were employed. This gives an aperture of f 2 to the instrument and hence yields an amount of energy sixteen times as great as that of the usual system of aperture f 8. As judged by the sharpness of the central image, the definition, even at this large aperture, leaves but little to be desired.

THE JOHNS HOPKINS UNIVERSITY,
BALTIMARE, MARYLAND,
DECEMBER, 1926.

A POLARIZATION PHOTOMETER EYEPIECE

By F. E. Wright

This instrument was constructed to serve primarily as an eyepiece on an astronomical telescope for use in a study of the amount of polarized light reflected by different parts of the Moon's surface under different angles of incident illumination. For this purpose a polarization photometer eyepiece is required in which the image of the object under test is viewed at the time the photometric readings are taken; otherwise the observer cannot be certain that he is measuring only the light reflected from the given point on the Moon's surface. Tests were first made with available polarization photometers, such as the small Koenig-Martens photometer, the double image plate of calcite, the Soleil plate, the Bertrand plate, and the biquartz-wedge plate; but none of these devices was entirely satisfactory for one reason or another. With the new eyepiece, however, good measurements were made with low eyepiece magnifications. Experience has shown that, with a slight modification, the arrangement can be applied to other problems of similar nature, wherever it is desirable that, at the time of measurement, the object be imaged in the photometric field.

The optical system of the new eyepiece is shown in the upper part of Fig. 1.[1] It consists essentially of a thin negative lens L_1 of 150 mm E.F., cemented to the front end of a calcite Wollaston prism W of slope angle 11°; to the opposite end of this prism is cemented a thin positive lens L_2 of 150 mm E.F. In addition there are two biprisms, A, with slope angles 7°30′ and, B, with slope angles 3°48′; also the low power eyepiece lens, C, and the Glan-Thompson polarizing prism, P. The apex of the biprism B is placed at the focus of the lens L_2, where it is viewed in the image plane dividing the field into two photometric halves. The biprism A is mounted on a sliding carriage so that its distance to B can be changed at will.

The converging rays from the telescope objective are rendered parallel by the negative lens L_1. On emerging from the Wollaston prism the parallel pencil is divided into two divergent plane polarized beams, one of which (i_ω) has its vibration plane vertical while the vibrations

[1] The optical parts for this eyepiece were made according to the writer's specifications by the Bausch and Lomb Optical Co., of Rochester, N. Y., and have been found, on test, to be entirely satisfactory.

of the second wave (i_2) are in a plane at right angles to the first. Each of these two parallel beams is brought to focus by the positive lens L_2 in the image plane, and with the same magnification as that produced by the telescope objective itself. The two converging bundles of light are deflected by the biprism A, so that the foci meet at or near the apex of the biprism B. As the biprism A approaches the biprism B the distance between the images changes. The movement of the biprism A is accomplished by rotation of the knurled head of a long screw whose threads engage the sliding carriage on which A is mounted.

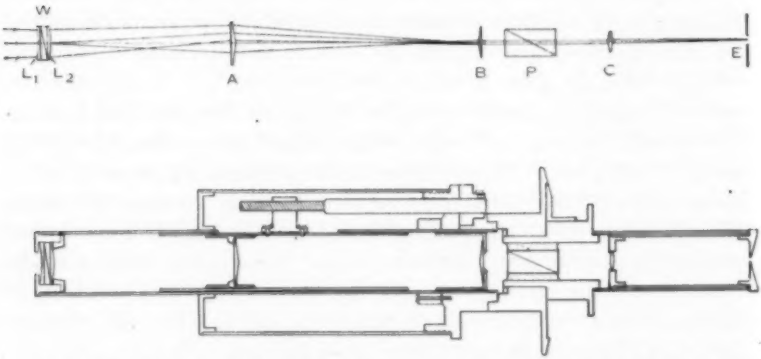

FIG. 1. *The upper part of this diagram presents the optical arrangement of the photometer. A negative lens, L_1, is cemented to the front side of the Wollaston prism, W, and a positive lens, L_2, to the opposite side. The biprism A is movable along the axis; the second biprism B is located in the image plane. The Thompson prism P is rotatable about the axis; C is the low power eyepiece lens, and E, the narrow exit pupil of the instrument.*

The lower part of the diagram is a sectional view of the completed eyepiece.

The polarizing prism P can be rotated in its mount and the angle which its principal plane includes with the principal planes of the Wollaston prism at the instant of exact photometric match in intensity of the two images of the detail on the Moon's surface can be read off directly on a graduated circle. With proper precautions to set the principal planes of the Wollaston prism in correct azimuth, the amount of polarized light present in the reflected beam can be computed; also its plane of vibration.

Dispersion effects in the Wollaston prism and in the biprisms introduce chromatic errors into the image which, however, with a low power eyepiece (E.F. 2 inches or more) are not serious. Simple computations show that the angles of emergence for ordinary and

extraordinary waves from the Wollaston prism of slope angle 11° and from the biprisms A and B are for the C, D, and F spectral lines:

TABLE 1. *Angles included with the axis by the ordinary and extraordinary waves (C, D, and F spectral lines) after passage through the Wollaston prism (i_ω, i_ϵ), the biprism A ($i_{\omega'}$, $i_{\epsilon'}$), and the biprism B ($i_{\omega''}$, $i_{\epsilon''}$).*

	C	D	F
i_ϵ	1° 53.76′	1° 56.14′	1° 58.62′
$i_{\epsilon'}$	−1° 58.98′	−1° 58.62′	−1° 57.72′
$i_{\epsilon''}$	0° 1.44′	0° 0.54′	−0° 1.62′
i_ω	−1° 53.28′	−1° 55.86′	−1° 58.08′
$i_{\omega'}$	1° 59.56′	1° 59.10′	1° 58.26′
$i_{\omega''}$	0° 2.04′	0° 1.08′	−0° 1.08′

In this table i_ϵ and i_ω are the angles included with the telescope axis by the extraordinary and ordinary principal waves on emerging from the Wollaston prism; $i_{\epsilon'}$ and $i_{\omega'}$ and $i_{\epsilon''}$, $i_{\omega''}$ the angles which they include with the telescope axis after emergence from the biprisms A and B respectively. The table shows that the spread of the principal rays for the spectral lines C to F is about 3′ of arc, a relatively large quantity. This chromatic effect can be much reduced by means of a suitable ray filter in case eyepieces of focal length less than two inches are required; also by making the biprism A of glass of higher dispersion than that of B. The values in Table 1 show clearly that the biprism A practically neutralizes the dispersion effects due to the Wollaston prism. It is possible, by choosing the glasses for the biprisms carefully and adjusting the slope angles, to reduce the chromatic aberration effects materially; but in the present instrument the biprisms are made of an ordinary crown glass of refractive index $n = 1.51$.

Although the photometer is designed primarily as an eyepiece on a large telescope it can serve directly as a low power telescope itself if the front negative lens L_1 is removed (Fig. 1). In this form it has been used to measure the amount of polarized light at different points in the sky, also in light reflected from different land surfaces and from vegetation, when viewed from a point above the ground.

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A MEASUREMENT OF THE EFFICIENCY OF THE EARS AS A MEANS OF DETECTING SHORT TIME INTERVALS

By A. Lowell Bennett

In a certain physical problem it was necessary to determine whether two pulses in different electrical circuits occurred simultaneously. To this end each circuit was connected to one pair of head phones and the ears used to estimate coincidence or non-coincidence of pulses. This led to the following experiments in which the minimum time interval detectable was measured.

The work was done at such short time intervals that it was impossible to distinguish the two pulses as separate. The effect was that of a single pulse, but the pulse would seem to come from the right or left, depending on whether the first pulse was received in the right or left ear respectively. This phenomenon is akin to the binaural effect investigated by Hornborstel and Wertheimer[1] et al.

APPARATUS

The apparatus was built around a one-sixth horsepower 120 volt direct current motor. The motor was mounted on a thick felt pad to prevent transmission of vibration to the bench on which it was mounted. A potentiometer control was arranged by means of which any constant speed from 60 to 6000 rpm could be obtained at will. A bakelite disk 12″ in diameter and 1″ thick was mounted securely on the motor shaft. A brass piece about one-eight inch thick was set radially in the circumference of the disk, and this was connected to the bushing on which the disk was mounted. A brush making contact with the bushing was mounted on the same base as the motor.

For stability the two brushes running on the circumference of the disk were mounted on an adjoining bench entirely independent of the motor. One brush was mounted in a fixed position, the other on a radial arm pivoted coaxially with the motor shaft. This arm was extended beyond the brush holder to a pointer moving over a scale of three feet radius. This scale was calibrated in hundred-thousandths of a second for a motor speed of 48 revolutions per second.

[1]Hornborstel und Wertheimer—Sitz. Königlich Preuss. Akad. der Wissen. p. 388; 1920.

On the rear end of the motor was placed a clockwork reduction gear, 48 to 1 ratio. A brass strip on the slow speed axle touched a stationary contact for approximately three-fourths of a revolution at every forty-eighth revolution of the motor. This contactor operated a light and also a relay. Alongside this light was placed another light flashing once a second, actuated by a seconds pendulum. The motor speed was adjusted until the lights maintained the same phase relation, whereupon the motor speed was known to be 48 revolutions per second. The wiring of the pulse-producing apparatus is shown in Fig. 1.

The time interval between the pulses could be regulated from twenty-five ten-thousandths (.0025) second to zero by merely shifting the movable brush, after the motor speed had been regulated to 48 rps. Since only one pulse in each phone was desired for an observation, the relay shown was introduced. This was actuated by the reduction gear contactor, so that only one set of pulses in 48, that is, one pulse a second, was produced. The reversing switch was introduced so that the first pulse could be produced in either the right or left ear.

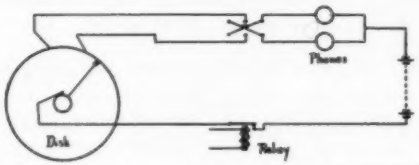

FIG. 1. *Wiring diagram of the pulse-producing apparatus.*

PROCEDURE

Two pairs of phones were connected, one at the setup for the operator, and the second in an adjoining room away from the noise of the motor, for the observer. The operator would close the reversing switch, sending the observer one pair of pulses, and the observer would press the right or left key, indicating to the operator by means of signal lamps, whether the sound seemed to come from the right or left. The operator recorded which way the switch was thrown and then checked right or wrong, according to the signal of the observer. In most of the observations successive pairs of pulses were sent at an interval of two seconds, this giving the operator sufficient time to record the way the switch was thrown and to check the observer. The order of successive pulses, right or left was made as heterogeneous as possible by the operator, so that the observer would have no inkling as to the side on which the next pulse would be received.

RESULTS

Readings were taken on eleven observers. The results were plotted, the log of the reciprocal of the time intervals at which the observations were taken being abscissas, and the per cent of observations correct ordinates. Fig. 2 is a typical curve. On each graph a curve or line was drawn to indicate the point where it seemed that the limit of 50% correct would be reached. Since there are only two possibilities, it is

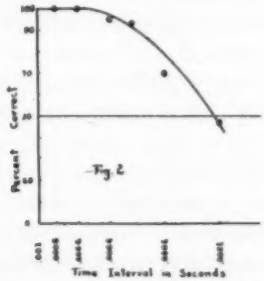

FIG. 2. *Typical curve showing decrease in accuracy with decrease in time interval.*

equally probable that the observer will get the result correct as incorrect when he is not certain. Hence 50% correct is taken as the limit of the observer's ability to distinguish the direction from which the pulse comes.

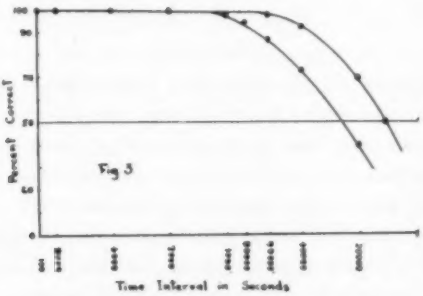

FIG. 3. *Effect of fatigue on the observer.*

The graphs show that every observer was able to distinguish with certainty at one one-thousandth second. Also they indicate that the limit of the average observer is one ten-thousandth second or less. In addition to these general conclusions, there are some interesting facts that stand out in the results of single observers. Fig. 3 shows the result

for observer No. 2, two curves having been drawn. The lower curve is plotted for the total number of observations, while the upper is plotted for the first part of the series. This seems to show that the observer's ability to discern is affected by fatigue, and becomes less keen after a few observations in each series. The same indication was in the results of other observers, but in none such a consistent variation.

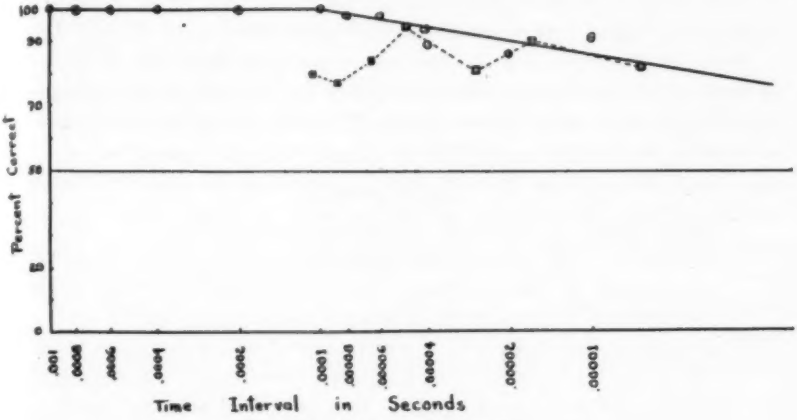

FIG. 4. *An outstanding record.*

Another outstanding result is shown in Fig. 4, the curve for observer No. 7. His limit seems to be much below that for the other observers. In order to check the results first obtained, a second run, shown dotted, was made. These results after the first three, check the first run within 5%. At 6.5 millionths of a second he was able to get 82% correct.

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DEFINITIONS OF PYROMETRIC TERMS

BY ASSOCIATION OF SCIENTIFIC APPARATUS MAKERS*

The following standardized definitions of pyrometric terms, as presented by the Industrial Group of the Association of Scientific Apparatus Makers, are recommended for general use.

Each of the terms was defined only after wide discussion with the Bureau of Standards and other authorities, and the definitions combine the thought of a representative group of those best qualified on nomenclature in the pyrometer field.

DEFINITIONS

1 Thermometer: A device for measuring temperatures.

2 Pyrometer: A device for measuring high temperatures. The term is applied to those devices, the principal use of which is for measuring temperatures above a red heat (about 500°C).

3 Resistance Thermometer: A thermometer which indicates temperature by means of the change with temperature of electrical resistance of one of its parts. It is a pyrometer when used at high temperatures (above 500°C), and in such case is preferably called resistance pyrometer.

4 Radiation Pyrometer: A pyrometer which indicates temperature by means of the change with temperature of the heat radiated by a hot body. As nearly as possible the total heat radiated is used. Usually this temperature is measured by a thermocouple.

5 Optical Pyrometer: A pyrometer which indicates temperature by means of the change with temperature of the light emitted by a hot body. As nearly as possible light of a single color (wave length) is ordinarily used.

6 Thermocouple: A pair of electrical conductors so joined as to produce a thermal emf when the junctions are at different temperatures. It consists of conductors of different material permanently joined at one end, the other ends being free to connect to an instrument for measuring emf.

7 Thermoelectric Pyrometer: A pyrometer which indicates temperature by means of the change with temperature of the emf.

*Adopted by the Industrial Group of the Association of Scientific Apparatus Makers at the Meeting on April 30, 1926.

of a thermocouple. It ordinarily consists of a thermocouple, a millivoltmeter (or other means of measuring emf) and connecting leads. The measuring instruments may be classified as follows:

Millivoltmeters
Potentiometers
Their Combination or Modifications

8 Hot Junction: That junction of a thermocouple which is subjected to the higher temperature.

9 Cold Junction: A junction of a thermocouple which is subjected to a lower temperature than the hot junction. This temperature is usually the temperature of reference.

10 Extension Leads: A pair of lead wires of such material that when connected to a thermocouple the effective cold junction will be removed to the other end of the leads: sometimes called compensating leads.

11 Accuracy: In specifying the accuracy of a pyrometer the maximum error shall be expressed as a percentage of the full scale reading; or it may be specified as the maximum number of degrees of temperature.

12 Sensitivity: The sensitivity of a pyrometer is its susceptibility to small changes of the temperature being measured. Specifically, it is defined as the smallest change in temperature which will cause a variation of one millimeter in the reading of the pyrometer.

A VACUUM TUBE POTENTIOMETER

By A. L. Fitch

In his book "The Thermionic Vacuum Tube" Van der Bijl discusses a circuit which with suitable modifications becomes one of the most versatile of electrical measuring circuits. He uses it to measure the amplifying power of vacuum tubes under varying conditions. As modified, it is essentially a vacuum tube voltmeter circuit and may be used wherever electrical quantities may be measured by equating potential drops.

To measure an impedance, it may be placed in series with a variable resistance and a source of single frequency alternating current. If the resistance is varied until the same difference of potential is found across it as across the unknown impedance, when measured by a voltmeter of very high impedance, it follows directly that the resistance is the absolute value of the impedance for the same current flows through both and the same difference of potential was found across them. The impedance may be any combination of resistances, inductances and capacities. Thus, if the unknown is a pure resistance, its value may be read directly from the variable resistance. If the unknown is a condenser

$$R = 1/Cp$$

where R is the variable resistance, when equal potentials are found, C is the capacity of the condenser and p is $2\pi f$, f being the frequency of the alternating current used. The capacity is known then, if the frequency is known.

If the unknown is a coil, its resistance may be determined by finding the condition for equal potential across it and a known resistance when direct current is impressed across them in series. Then by placing the resistance and coil in series across a source of single frequency alternating current the impedance of the coil may be determined. From this

$$R^2 = r^2 + L^2p^2$$

where r is the direct current resistance of the coil and L its inductance. This is true, of course, only when the direct current resistance is equal to the alternating current resistance, that is for air core coils at low frequencies.

If the resistance of the coil is very low and the inductance is set at $\frac{1}{2\pi}$ henries, there results

$$R=\frac{2\pi f}{2\pi}=f \text{ henries}$$

or the resistance measured in ohms is the frequency of the alternating current in cycles per second. Multiples of $1/2\pi$ henries may be used if desired to extend the range of the instrument. This is thought to be a new method of measuring the frequency of alternating currents.

If the unknown impedance is made a resistance equal to R but connected to a different source of alternating current, the current in the second circuit may be read from a meter placed in the first, even though the frequencies are radically different. A meter calibrated at 60 cycles is therefore accurate at other frequencies with this arrangement.

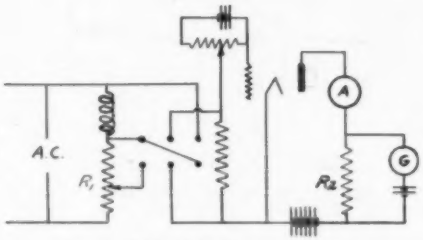

FIG. 1. *The single tube potentiometer.*

Many other uses for such a circuit might be cited but enough have been given to show its value in the electrical measurements laboratory.

Two circuits have been devised for use in the above mentioned methods. The first circuit shown in Fig. 1 uses one vacuum tube. Any good tube is connected with a variable grid potential through a high resistance grid leak. Across the grid leak a double pole double throw switch is connected. By means of this switch, one is able to impress across the grid leak and so on the grid circuit of the tube the potentials of the end points of the switch. These end points are connected across a resistance and an impedance in series. When the switch is thrown to the left, the difference of potential across a known resistance is applied to the tube. When the switch is thrown to the right the difference of potential across the impedance is applied to the tube. The plate is connected through a suitable plate battery and milammeter to a

divided circuit consisting of a dry cell and galvanometer in parallel with a variable resistance. Care must be taken that the cell is poled so that current from it will oppose that due to the plate battery through the galvanometer.

The grid potential is adjusted with the switch open until the milammeter in the plate circuit reads zero. However, this reading does not enter into the computations in any way so great care is not necessary. The switch is then closed to the right. This places an alternating difference of potential of single frequency across the grid leak, which produces a pulsating current in the plate circuit and so causes the milammeter to read higher. The resistance R_2 is then adjusted until the galvanometer reads zero. If the switch is now thrown to the left and the galvanometer still reads zero the same difference of potential

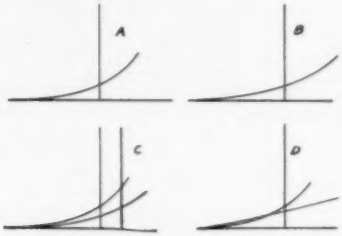

FIG. 2. *Characteristic curves for two tubes.*

was placed across the grid leak of the tube in the two positions of the switch. Usually R_1 will have to be adjusted to keep the galvanometer reading zero on both settings of the switch. When this condition has been attained R_1 is the absolute value of the impedance of the unknown. This is true because the same current flows through R_1 and the unknown and the same difference of potential was found across them.

The same results may be obtained by a second circuit shown as Fig. 3, which uses two vacuum tubes and does away with the necessity of throwing a switch back and forth. Two similar vacuum tubes are connected to a common plate battery through equal resistances. Across these resistances is connected a galvanometer. The grid circuits of the tubes are provided with variable grid potentials. A variable resistance in series with a milammeter is also placed in the plate circuit of one of the tubes. The two impedances to be compared are connected in series in the grid circuits of the two tubes, one in either grid circuit. One of these impedances will usually be a variable resistance. Across

these impedances is connected a source of alternating current of single frequency through a switch.

If the tubes are alike in all characteristics, equal negative potentials will be required in the grid circuits to reduce the plate currents through the tubes to zero, and for equal potentials on the grids equal currents will flow in the plate circuits. These equal currents will cause equal differences of potential across the equal resistances and so cause the galvanometer to read zero. However, tubes that have equal constants are very difficult to find. Usually two tubes of the same type will be found to have slightly different characteristics. However, with different grid potentials and a variable resistance in the plate circuit of one of

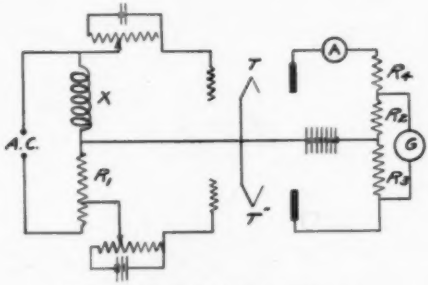

FIG. 3. *The double tube potentiometer.*

the tubes, two points may be found on the "grid potential-plate current" curves of the tubes that are the same. These curves are shown in Fig. 2 as *a* and *b*. In Fig. 2c these curves are superposed with the grid potentials coinciding at which the plate currents are reduced to zero. This gives one common point. The other point is obtained by placing a suitable resistance in the plate circuit of one of the tubes to lower its "grid potential-plate current" curve so that it crosses that of the other tube to the left of the zero potential line. This is shown in Fig. 2d. This crossing will occur at a very definite plate current value corresponding to a very definite grid potential value. The galvanometer will then read zero for these two points, *only*, when equal potentials are placed in the grid circuits.

In operation the circuits are connected as shown with the switch open. The grid potential of tube T' is changed until the milammeter reads zero. This means no current flows through the upper of the two equal resistances in the plate circuits. The galvanometer will then deflect due to current through the lower resistance in the other plate

circuit. The grid potential of T'' is then changed until the galvanometer reads zero. This will be true when no current flows in either resistance. The switch is then closed with equal resistances in the grid circuits and the current through them is varied until the milammeter reads about one-fourth of what it did with no potential on the grid of that tube. This is necessary in order to have the grid negative at all times. If the milammeter should read the same under these conditions as with no potential on the grid it would mean the grid was positive part of the time because the milammeter is operating on rectified current. It is necessary therefore that the milammeter reading be so low that the maximum current through it on the peak of the wave will correspond to a grid potential that is negative. If the grid should become positive current would flow from it to the filament and so lower the input impedance of the tube. When the milammeter reads as described the

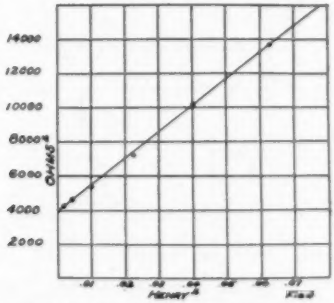

FIG. 4. *Curve of impedance and inductance on lighting circuit.*

resistance R_4 is adjusted until the galvanometer stands at zero and the milammeter is read very carefully. Since equal resistances were in the grid circuits for this reading and equal currents flowed through them there must have been equal alternating potentials applied to the tubes. At any future time that an alternating potential has been applied to this tube to cause the milammeter to read the same, the same alternating potential has been applied to the grid. If there is at the same time a potential applied to the other tube which will cause the galvanometer to read zero that potential is the same as applied to the grid of the first tube.

This circuit is a little difficult to adjust but once adjusted readings may be taken very rapidly.

The curve plotted in Fig. 4 was plotted from data taken with a Leeds and Northrup Brook's Inductometer placed in the lighting

circuit. The ordinates are the squares of the resistances which gave equal potentials with the inductometer settings and the abcissas are the squares of the inductometer settings. The intercept is therefore the square of the direct current resistance and the slope of the line is the square of the angular velocity. From this curve the direct current resistance is 64 ohms and the frequency is 61.8 cycles per second.

The curve plotted in Fig. 5 was from data with the same inductometer as for Fig. 3 placed in series with an audio oscillator rated as 1000 cycles

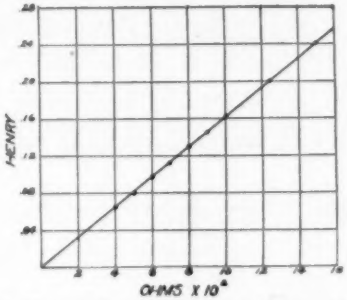

FIG. 5. *Inductance plotted against impedance for 1,000 cycles.*

per second. The ordinates are the inductometer settings and the abcissas are the resistance settings for equal potential drops. The resistance of the coil is so low that it may be neglected. The slope of the line is the angular velocity from which the frequency is found to be 1000 cycles. It will also be seen that the line passes through the point 1000 ohms and $\frac{1}{2}^{r}$ henries.

These data were taken with the two tube circuit described but the other circuit would have given practically the same lines.

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CONSTRUCTION OF MERCURY ARC LAMPS FOR LABORATORY USE

By D. S. Ainslie

The lamp and method of construction described in the following article, were designed so as to be as simple as possible, in order to render mercury arc lamps available in laboratories with a limited equipment for this type of work. The lamp was about 20 cm long and operated with the arc vertical giving a source of light suitable for spectroscopic experiments.

A diagram of the lamp is given in Fig. 1. The body of the lamp was constructed from cylindrical pyrex glass tubing 1.6 cm internal

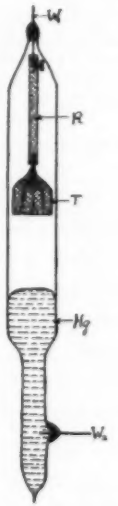

Fig. 1. *Mercury arc lamp.*

diameter and about 1.9 cm external diameter. For the positive terminal (T) a thin wall iron cylindrical terminal obtained from an old Cooper Hewitt lamp, was employed. This was joined to a tungsten lead in wire (W_1) by means of a short iron rod (R). The larger tube was then drawn down and joined to a short length of 6 mm pyrex glass tubing into which a tungsten wire (W_2) had been sealed. The lamp was connected up as part of a glass system shown in Fig. 2.

Before commencing the exhaustion, the lamp was carefully cleaned by washing it and the tubes connected thereto, with dilute nitric acid, distilled water and absolute alcohol in the order indicated. Preliminary work showed that it was important that only absolute alcohol be used as a drying agent. The apparatus was then thoroughly dried and the desired amount of mercury was introduced into the reservoir (A). A Cenco-Supervac pump unit was connected to the system at (C) by means of short length of rubber pressure tubing. The exhaustion was carried on for two hours or more and during this process the lamp part was heated to a dull red by means of a cylindrical electrical heater. Before sealing off, the mercury in the reservoir (A) was thoroughly heated and then introduced into the lamp by tilting the apparatus. The lamp was sealed off at (O) leaving the reservoir and connecting tube available for another lamp.

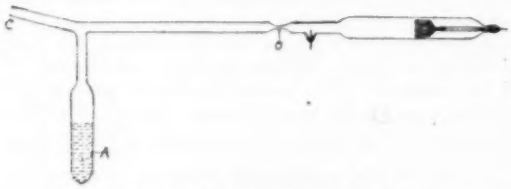

FIG. 2. *Lamp with glass apparatus used in evacuation.*

For use in the laboratory the lamp was connected in series, with a suitable resistance, to the terminals of a 110-volt direct circuit. The lamp was mounted in a stand so that it could be turned in a horizontal position, with the terminal (W_2) downward, to complete the circuit and then tilted back into a vertical position. The current consumption was approximately 3 amperes with a fall of potential across the terminals of 16 to 20 volts. The efficiency of the lamp as a source of light was increased by attaching thin copper fins opposite the terminal (T) and the top of the mercury reservoir. With this feature, which is not shown in the diagram, an operating current of 5 amperes was made possible with a consequent enhancement of the red and infrared portions of the spectrum.

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A STUDY OF THE ENERGY DISTRIBUTION AND EFFICIENCY OF THE QUARTZ MERCURY ARC AS FUNCTIONS OF ARC VOLTAGE, CURRENT DENSITY AND TUBE DIAMETER

By Donald C. Stockbarger*

ABSTRACT

By employing the filter-thermopile method of making radiation analyses, the energy distributions of the radiation emitted by a number of special quartz mercury arcs have been determined over wide ranges of arc voltage at several constant current densities. The results indicate that high voltage, high current density and large tube diameter are favorable for high percentage of ultraviolet radiation. For any given tube diameter and current density, there exists an arc voltage at which the infrared percentage reaches a maximum. The visible and near and far ultraviolet percentages exhibit corresponding minima. The infrared maximum appears at lower voltages as the current density or tube diameter is increased.

It is shown that intensity is a function of current and arc voltage treated as separate variables, rather than of the product of these two. The intensity of a spectral group may increase, remain constant or decrease with increasing input to the burner.

The total efficiency expressed as the ratio of radiant power to electrical input increases with increasing arc voltage, current density and tube diameter. Under given electrical conditions the efficiency can be increased by heating the luminous tube.

I. INTRODUCTION

Because of the success of the quartz mercury arc in meeting the requirements of photochemical and similar investigations, its characteristics have been given the attention of a number of investigators. For convenience we may divide the previous studies into three groups. The first comprises all in which energy distribution or intensity measurements were made at one or two arbitrary power inputs, and is of little more than historical interest insofar as the problem under consideration is concerned. Such studies have been made by Pflüger,[1] Ladenburg,[2] Lux,[3] Hallwachs,[4] Bell,[5] Winther,[6] Kowalski,[7] Souder,[8] Koppius[9] and Reeve.[10]

The second group made by Vaillant,[11] Küch and Retschinsky,[12,13,14] Pflüger,[15] Fabry and Buisson,[16] Henri,[17,18] Grebe,[19] Tian,[20] Coblentz,[21] Boll,[22] Coblentz, Long and Kahler,[23] and Coblentz and Kahler,[24] include studies of the effect of power input on the characteristics of the mercury arc. In these studies values of the derivatives of intensities with respect to a function of the current and arc voltage were obtained. This

* Taken in part from a Thesis presented to the Massachusetts Institute of Technology in partial fulfillment of the requirements for the degree of Doctor of Science.

function is the product of the current and arc voltage. The input can be increased in a number of ways by varying the current and arc voltage either separately or together. It is obvious that if intensity is not a single-valued function of input an attempt to obtain a derivative of intensity with respect to input may yield any one of a large number of possible values.

That the intensity is not a single-valued function of input has been proved by experiments of the third kind. In these which have been carried out by Athanasiu,[25] Harrison and Forbes,[26] and Forbes and Harrison,[27] line or group intensities have been measured at different power inputs, the current or arc voltage being held constant. The intensity-input curves obtained at constant current were not the same as those obtained at constant arc voltage.

In general the relative values of current and arc voltage are determined by the series resistance and the temperature of the arc. The latter can be varied by altering ventilation conditions. Assuming constant supply voltage and series resistance, the current will decrease and the arc voltage will increase if the temperature is allowed to increase, and vice versa. The current and arc voltage are determined at each value of input if the ventilation remains constant and a curve showing the relation between the two input factors is known as the stationary characteristic curve. Inasmuch as the stationary characteristics of quartz mercury arcs of the same design operated under similar thermal conditions are approximately the same, the values of the derivatives with respect to input have some meaning. Because all arcs are not of similar design and are not operated under identical ventilation conditions, only studies of the third type can be of practical value. They cannot be of general value, however, unless another variable, viz., tube design, is taken into consideration.

The investigation herein reported had for its primary object: first, to determine the relation between the radiation characteristics of the quartz mercury arc and the current and arc voltage treated as separate variables; and, second, to study the effect on these characteristics caused by varying the arc tube diameter.

II. INSTRUMENTS AND METHODS

Ten special lamps, or "burners" as they are often called, were carefully constructed of selected quartz stock and exhausted in the Cooper Hewitt Laboratory in order to attain the highest possible quality.

Table 1 gives the dimensions of the burners. All of these were of the vertical, direct current type. The anodes consisted of heavy pieces of tungsten wire formed into "pan-cake" coils with their planes perpendicular to the arc columns. All seals were of the tungsten-in-glass-to-quartz type now commonly employed in commercial apparatus of this kind.

TABLE 1. *Principal dimensions of the special burners.*

Burner number	Arc length	Arc diameter	Cathode diameter	Cathode length
SA1	4 in.	0.38 in.	0.38 in.	1.5 in.
SA2	4	0.38	0.69	1.5
SB1	4	0.50	0.50	1.5
SB2	4	0.50	0.88	1.5
SB3	4	0.50	1.19	1.5
SC1	4	0.63	0.63	1.5
SC2	4	0.63	1.31	1.5
SD	4	0.88	1.63	1.5
SE	4	1.19	2.38	1.5

Special Burner No. 1. Similar to SC1.

Throughout this work the radiation measurements were made by means of a 25 element copper-constantan thermopile having a continuous absorbing surface 3×25 mm in area and a Leeds and Northrup high sensitivity, low resistance galvanometer. The receiver of the thermopile was rendered nonselective by smoking it over a sperm candle.

The analyses were made with the aid of three kinds of filters, viz., quartz water cell, Noviol O glass and G86B glass, the procedure being to compare the intensities of filtered radiation and total radiation. The water cells were constructed entirely of fused quartz, and had practically plane ground and polished windows. The distance between plates was 11 mm; the diameter 50 mm. The Noviol O and G86B glasses were 50 mm square and 2 and 1 mm thick respectively.

The quartz water cell when filled with distilled water should be transparent to all radiations between 1850A and 14,000A. Kreusler[28] found that a 17 mm layer of distilled water in a quartz cell transmitted 28.5 per cent at 1869A, and Aschkinass[29] found that a 10 mm layer transmitted infrared radiation of wave lengths shorter than 14,500A. There may be some question as to the transmission limits of the fused quartz, but this much can be said with a fair degree of certainty:

the quartz being of the same high quality as that of the mercury arc tubes themselves, it was able to transmit all radiations transmitted by the latter.

The transmission curves of Noviol O[30] and G86B[31] show that the former is opaque to radiations of wave lengths shorter than 3700A, and transmits 10 per cent at 3800A, and that the latter is opaque beyond 2700A, and transmits 14 per cent at 2900A. Both glasses have high transmissions in the infrared well beyond 14,000A so that when used with a water cell their infrared absorption need not be considered.

Since practically all of the energy in the mercury arc spectrum is concentrated in comparatively widely separated intense lines or groups of lines, it was easy to fix with fair accuracy the limits of the spectral regions studied. These limits were: limit of quartz to 14,000A, 14,000A to 3800A, 3800A to 2900A and 2900A to limit of quartz and water for infrared, visible, near ultraviolet and far ultraviolet, respectively. The use of the words "infrared" and "visible" may be somewhat misleading in that the actual boundary lies near 8000A. While it would have been possible to employ an additional filter to study the energy between 8000A and 14,000A, this was not done in this investigation because there are comparatively few lines in this region, and interest was centered in the near and far ultraviolet radiations.

The lamp house was constructed of asbestos wood and was used without a back in order to eliminate errors due to reflection. On the front was mounted a copper diaphragm having an aperture of such length as to cut off all radiations from the tungsten anode and the region just above the cathode, and of such width as to permit the passage of radiation from the entire diameter of the largest tube studied. At the bottom of the box and surrounding the cathode an electrical heating coil was placed to assist in regulating the pressure within the arc. At some distance in the rear a large piece of black canton flannel was hung to prevent reflection from the wall. The distilled water for the quartz cells was prepared by means of a "conductivity water" still in which ordinary distilled water was treated with caustic potassium permanganate and carefully redistilled. An estimate of the filter transmission was obtained by determining the ratio of the intensities of radiation which had been transmitted by two filters and by one filter, respectively. In each case two identical filters were employed. If the absorption were uniform between, and sharp at, the limits this method would be exact. Since these conditions do not exist, it is obvious that if the energy distribution changes the observed trans-

mission will also change. This was in fact found to be the case so that it was necessary to determine the transmission under each input condition.

III. EXPERIMENTAL RESULTS AND DISCUSSION

In all energy distribution studies the percentage of infrared was found to increase with arc voltage at constant current, to reach a maximum and then to decrease, as illustrated by Figs. 1 and 2. The

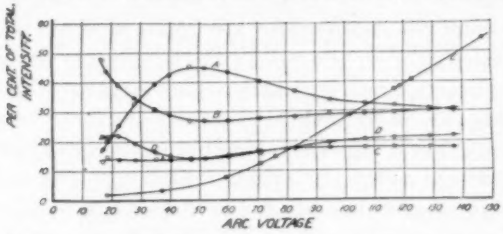

FIG. 1. *Variation of energy distribution and visible intensity with arc voltage for special burner No. 1 operated at 2.0 amperes. A, per cent infrared; B, per cent visible; C, per cent near ultraviolet; D, per cent far ultraviolet; E, intensity of visible.*

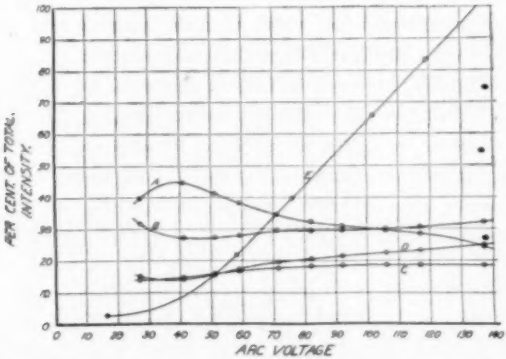

FIG. 2. *Variation of energy distribution and visible intensity with arc voltage for special burner No. 1 operated at 3.5 amperes. A, per cent infrared; B, per cent visible; C, per cent near ultraviolet; D, per cent far ultraviolet; E, intensity of visible.*

other components exhibited more or less marked minima corresponding to the infrared maximum. Increasing either the current density or the tube diameter caused this maximum to appear at a lower arc voltage.

In general, high arc voltage, high current density and large tube diameter were found to be favorable conditions for high near and far ultraviolet percentage. The far ultraviolet component is relatively

greater at low than at intermediate arc voltages. This appears to agree well with the statements frequently made that the quartz mercury arc is most powerful as a source of short wave length radiation when operated at very low arc voltages. The basis for this generally accepted belief lies in the fact that two of the strongest lines, 1849 and 2537A, are easily absorbed and practically disappear when the arc voltage is large. The other fact, viz., that the remaining ultraviolet lines rapidly increase with the arc voltage is often overlooked. As is shown by the energy distribution curves, the high pressure arc is very rich in far ultraviolet radiation. It is true that certain photochemical reactions which depend largely upon the 1849 line do proceed more slowly at the higher voltages, but this is proof only that the energy distribution within the far ultraviolet changes greatly as the voltage increases, and not that the far ultraviolet component as a whole decreases.

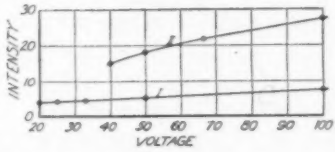

FIG. 3. *Variation of visible intensity with arc voltage at constant power input for special burner No. 1. I, 100 watts. II, 200 watts.*

When any two of the three variables, arc voltage, current density and tube diameter, were fixed, the intensities of ultraviolet and total radiation were found in general to increase with an increase in the third variable. At constant power input, the intensities increased with increasing arc voltage and therefore decreased with increasing current density, showing that the intensity is a function of current and arc voltage treated as separate variables. The latter effect had been noticed a number of times in the course of the earliest work but was not given serious consideration until early in 1923, when the data for Fig. 3 were obtained. Similar curves for the ultraviolet components can be drawn from data at hand.

The efficiency was defined arbitrarily as the ratio of total radiant power at a distance of one meter to electrical input, the length of arc column from which the radiation was taken being constant. This was found in general to increase with arc voltage, current density and tube diameter, as illustrated by Figs. 4 to 6. Since the percentage of ultraviolet also increases with these variables it is readily seen that the

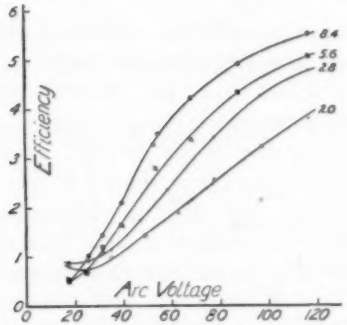

FIG. 4. *Total radiant efficiency in arbitrary units as a function of arc voltage at several constant currents for burner* SC2.

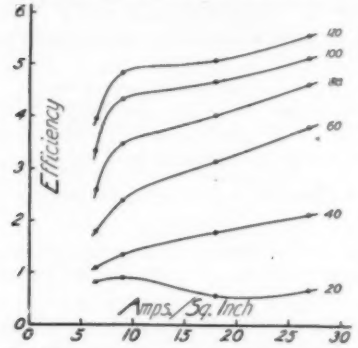

FIG. 5. *Total radiant efficiency in arbitrary units as a function of current density at several constant arc voltages for burner* SC2

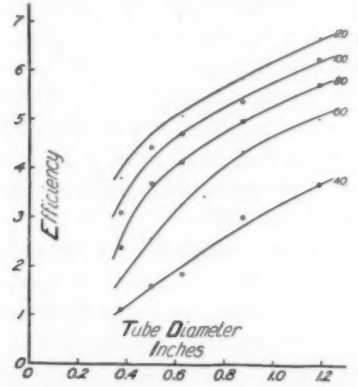

FIG. 6. *Total radiant efficiency in arbitrary units as a function of tube diameter at several constant arc voltages and at a constant current density of 18 amperes per square inch.*

efficiency for this region must be comparatively high for large diameter arcs operated at high current density and high arc voltage.

The increased efficiency obtained by increasing the diameter of the arc tube, the arc voltage or the current density appears to have been due to raising the temperature of the arc. The efficiency of any one of the lamps operated at constant arc voltage and current could be increased or decreased by heating or cooling the luminous tube. In some cases the change was about 50 per cent.

All of the findings indicate that a quartz mercury arc used primarily as an ultraviolet source should have as large a tube diameter as possible; that the arc voltage and current should be as high as the construction of the lamp will permit; and that the luminous tube should be maintained at a high temperature.

Thanks are due Professor H. M. Goodwin for his kindly interest and suggestions throughout the course of this work, and for securing appropriations covering the cost of some of the instruments employed; to Mr. A. L. M. Dingee for his assistance in making some of the more difficult measurements; and to the Cooper Hewitt Electric Company for fabricating the special burners and for very considerable financial aid. I wish particularly to thank Mr. R. D. Mailey and Mr. L. J. Buttolph of the Cooper Hewitt Electric Company for their cooperation and helpful suggestions.

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A Manual of Radioactivity. By George Hevesy (Copenhagen) and Fritz Paneth (Berlin). Translated by Robert W. Lawson. xix+252 pages. Oxford University Press. $5.00 net. 1926.

This translation is really a new edition of the book, first published by the authors in 1922, the purpose of which was to present a *manual* of radioactivity.

The material is divided into twenty-seven chapters. After a short introductory chapter come five chapters devoted, respectively, to the various "rays": α-rays, β-rays, γ-rays, secondary rays and recoil rays. Chapter VII gives a summary of the constitution of the atom and its relation to radioactive rays. The general facts of radioactive disintegrations and the necessary mathematical theory are covered in Chapters VIII, IX and X. A short chapter, XI, discusses the determination of "half-value" periods. The chemical properties of the radio-element, isotopy, the chemical behavior of extremely small quantities of a substance and the use of radio elements as indicators occupy Chapters XII to XVI. Among the topics included in the remaining chapters may be mentioned: Isotopy and Atomic Constitutions; Electronic and Nuclear Properties of the Atom; Isotopes and Their Separation; Mixed and Pure Elements; Description of Chemical Elements and the Structure of the Nucleus; The Preparation of Radioactive Material; Effects of Rays from Radium; Radioactivity and Geology.

One of the most valuable features of the work is the comprehensive literature citation, covering the period 1916 to 1925. The method of treatment is clear and systematic and assumes no special previous knowledge of the subject on the part of the reader. The book should prove equally valuable as reference or text.

F. K. RICHTMYER